FROM: AFCESA/CES
139 Barnes Drive, Suite 1
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SUBJECT: **Engineering Technical Letter 97-9: Criteria and Guidance for C-17 Contingency and Training Operations on Semi-Prepared Airfields**

1. Purpose. This ETL provides criteria and guidance for design, construction, maintenance, and evaluation of semi-prepared airfields for contingency and training operations of C-17 aircraft. It supersedes ETL 97-9 dated 30 June 1997. Visual Flight Rules (VFR) apply for the dimensional criteria in Section 3.

2. Application: All Department of Defense organizations responsible for design, construction, maintenance, and evaluation of airfields.

2.1 Effective Date: Immediately. Remains in effect until these requirements are incorporated into FM 5-430-00-01,2/AFJPAM 32-8013, *Planning and Design of Airfields in the Theater of Operations,* EI 02C013 (TM 5-803-7), *Airfield and Heliport Planning and Design,* and/or AFJMAN 32-1014, *Airfield Pavement Design.*

2.2. Ultimate Recipients:

- Base Civil Engineers and Red Horse Units responsible for design, construction, and maintenance of airfields.
- Army Corps of Engineers, Marine, and Navy offices responsible for design, maintenance, and construction of airfields.

3. Criteria and Guidance. Criteria and guidance attached are based on very limited data. Structural and flight tests were accomplished at only one AM-2 location, three mechanically stabilized locations with similar soil types and climatic conditions and one cement stabilized location. Data on other soil types and climates are needed to assure world wide capability for contingency situations. Friction data is based on tests at a variety of locations; however, additional testing is needed to increase confidence.

NOTE

This ETL will be revised as additional data becomes available. Users should reference all subsequent changes to this ETL to obtain current guidance.

4. Contacts. Mr. Jim Greene, DSN 523-6334, commercial (850)283-6334; or Mr. Dick Smith, DSN 523-6084, commercial (850)283-6084.

William G. Schauz, Colonel, USAF
Director of Technical Support

2 Atch
1. *Criteria for Design, Maintenance, and Evaluation of Semi-Prepared Airfields for Contingency Operations of the C-17 Aircraft*
2. Distribution List

Criteria
for
Design, Maintenance, and Evaluation
of
Semi-Prepared Airfields
for
Contingency Operations of the C-17 Aircraft

(15 October 1997)

Contents

Section 1. Introduction

1.1. References:

- FM 5-430-00-01, 02/ AFJPAM 32-8013, Volumes I and II, *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations*
- EI 02C013 (TM 5-803-7) / AFJMAN 32-1013, *Airfield and Heliport Planning and Design*
- Pavement-Transportation Computer Aided Structural Engineering (PCASE) design and evaluation computer programs:
  - Dynamic Cone Penetrometer (DCP) program is used to plot DCP data and establish soil layer thicknesses and strengths.
  - Unsurfaced Design (UNSURF) program is used to aid in design of semi-prepared airfields.
  - Unsurfaced Evaluation (UNSEVA) program is used to determine aircraft allowable gross weights and/or passes based upon layer structures established with the DCP.
- *Airfield Friction Meter MK2 Operating Instructions*, Rev 3.1x, Issue 3, Bowmonk Ltd., Norwich, England, 1995

PCASE programs are available on the World Wide WEB (WWW) at **http://pavement.wes.army.mil/pcase.html**. For access, open a Uniform Resource Listing/Locator (URL) to the address, which will jump to the PCASE homepage for computer program access. For File Transfer Protocol (FTP) Anonymous Network Access, FTP to: **pavement.wes.army.mil** using 'anonymous' as the log in name, and 'pcase' as the password. Change directory to 'pub' (cd pub) and look at directory contents (ls). Change transfer type to binary (binary) and then use the 'get' command to retrieve any file you wish. For example, if you wish to get the file 'unsurf1_0.exe' then type 'get unsurf1_0.exe".

Note: All programs on the WWW homepage and FTP site are compressed executables. Upon first time execution of any program, multiple files will be extracted, therefore; **it is vital that each program is put in its own subdirectory with no other files when it is first executed**.

1.2. Definitions.

1.2.1. Acronyms:

- ACN – Aircraft Classification Number
- CBR – California Bearing Ratio
- DCP – Dynamic Cone Penetrometer
- ETL – Engineering Technical Letter
- FASSI – Frost Area Soil Support Index
- FTP – File Transfer Protocol
- HMMWV – High Mobility Multi-purpose Wheeled Vehicle
- PCASE – Pavement-Transportation Computer Aided Structural Design and Evaluation computer Programs

- PCN – Pavement Classification Number
- RCR –Runway Condition Rating
- RRM – Rolling Resistant Material
- SPACI – Semi-prepared Airfield Condition Index
- SST – Special Tactics Team
- UNSEVA – Unsurfaced Evaluation Program
- UNSURF – Unsurfaced Design Program
- USCS – Unified Soil Classification System
- VAMP – Visual Assault Zone Marker Panel
- VFR – Visual Flight Rules

1.2.2. Terms:

- Pass – The movement of an aircraft over a specific spot or location on a pavement feature.
- Base or Subbase Courses – Natural or processed materials placed on the subgrade.
- Subgrade – Natural in-place soil upon which a pavement, base, or subbase course is constructed.
- Compacted Subgrade – The upper part of the subgrade.

1.3. Airfield Types. The C-17 can operate on paved or semi-prepared airfields and matting. Paved airfields consist of conventional rigid and flexible pavements and are generally used for routine operations. A "semi-prepared" airfield refers to an unpaved airfield. The amount of engineering effort required to develop a semi-prepared airfield depends on the planned operation, the service life needed to support these operations, and the existing soil and weather conditions. Semi-prepared construction/maintenance preparations may range from those sufficient for limited use to those required for continuous routine operations. Options for surface preparation may include stabilization, addition of an aggregate course, compaction of in-place soils, or matting.

1.4. Types of Operations. Three types of operations are anticipated with the C-17 aircraft. Visual flight rules apply for contingency and training operations.

- Routine operations consist of normal day to day operations conducted on paved surfaces.
- Contingency operations are normally short term operations connected with conflicts or emergencies. Airfields for contingency operations can be paved or unpaved. Since operations are limited, structural requirements are not as great. In addition, higher risk to aircraft and personnel may be justified, so requirements such as clearances, are not as stringent.
- Training operations involve training for contingency situations. They can be conducted on paved or unpaved runways (semi-prepared). Since training airfields are for long-term operations, semi-prepared surface structural and dimensional requirements are more stringent than for contingency airfields. Stabilization may be required.

1.5. Purpose. The purpose of this document is to provide criteria and guidance to DoD organizations concerned with planning, design, construction, evaluation and maintenance of semi-prepared airfields for contingency and training operations of the C-17. This document will remain in effect until the criteria and data are incorporated into FM 5-430-00-01.02/AFJPAM 32-8013, Volumes I and II, *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations*. Criteria for planning and design of airfields for C-17 routine and training operations will be contained in EI 02C013 / AFJMAN 32-1013.

Section 2. Aircraft Characteristics. (See Figures 2.1 and 2.2 for horizontal, vertical, and landing gear dimensions.)

Horizontal Dimensions

Length—174.0 feet
Height—55 feet, 1 inch
Wing
Span (winglet tips)—169 feet, 9 inches
Location of outboard engine—45 feet, 9 inches
Location of inboard engines—24 feet, 5 inches

Vertical Clearances

Top of fuselage—24 feet, 1 inch
Top of vertical stabilizer—55 feet, 1 inch
Bottom of wing tip—13 feet, 10 inches
Bottom of outboard engine—7 feet, 9 inches
Bottom of inboard engine—8 feet, 11 inches
Lowest point on fuselage (main gear pod)—12 inches

Landing Gear Dimensions

The main landing gear consists of dual struts on each side of the aircraft, with three wheels on each strut. The nose gear consists of a single strut with two wheels. Dimensions are shown below and in Figure 2.2.

Distance between nose gear tires—2 feet, 5 inches(center-to-center)
Center of nose gear to center of main gear—62 feet, 2 inches
Tread –33 feet, 8 inches
Distance between main gear tires---varies (see Figure 2.2)

Aircraft Weights

Maximum gross weight on paved surfaces--586,000 pounds
Maximum contingency operating weight on semi-prepared surfaces--447,000 pounds
Maximum operating weight on matting--560,000 pounds
Operating weight--279,000 pounds

Landing Gear Static Loads

Percent load on each main gear strut--23 %
Percent load on nose gear--8%

Main Gear Characteristics

Weight (Kips)	Strut Load(Kips)	Wheel Load (Kips)	Contact Area (Sq. In.)	Tire Pressure (psi)	Contact Area Width (In.)
586	134.8	44.9	320	138	15.7
560	128.8	42.9	310	138	15.5
447	102.8	34.3	250	138	13.9
279	64.2	21.4	155	138	9.8

Nose Gear Characteristics

Weight (Kips)	Strut Load(Kips)	Wheel Load (Kips)	Contact Area (Sq. In.)	Tire Pressure (psi)	Contact Area Width (In.)
586	46.9	23.4	150	155	10.7
560	44.8	22.4	145	155	10.6
447	35.8	17.9	115	155	9.4
279	22.3	11.2	72	155	7.5

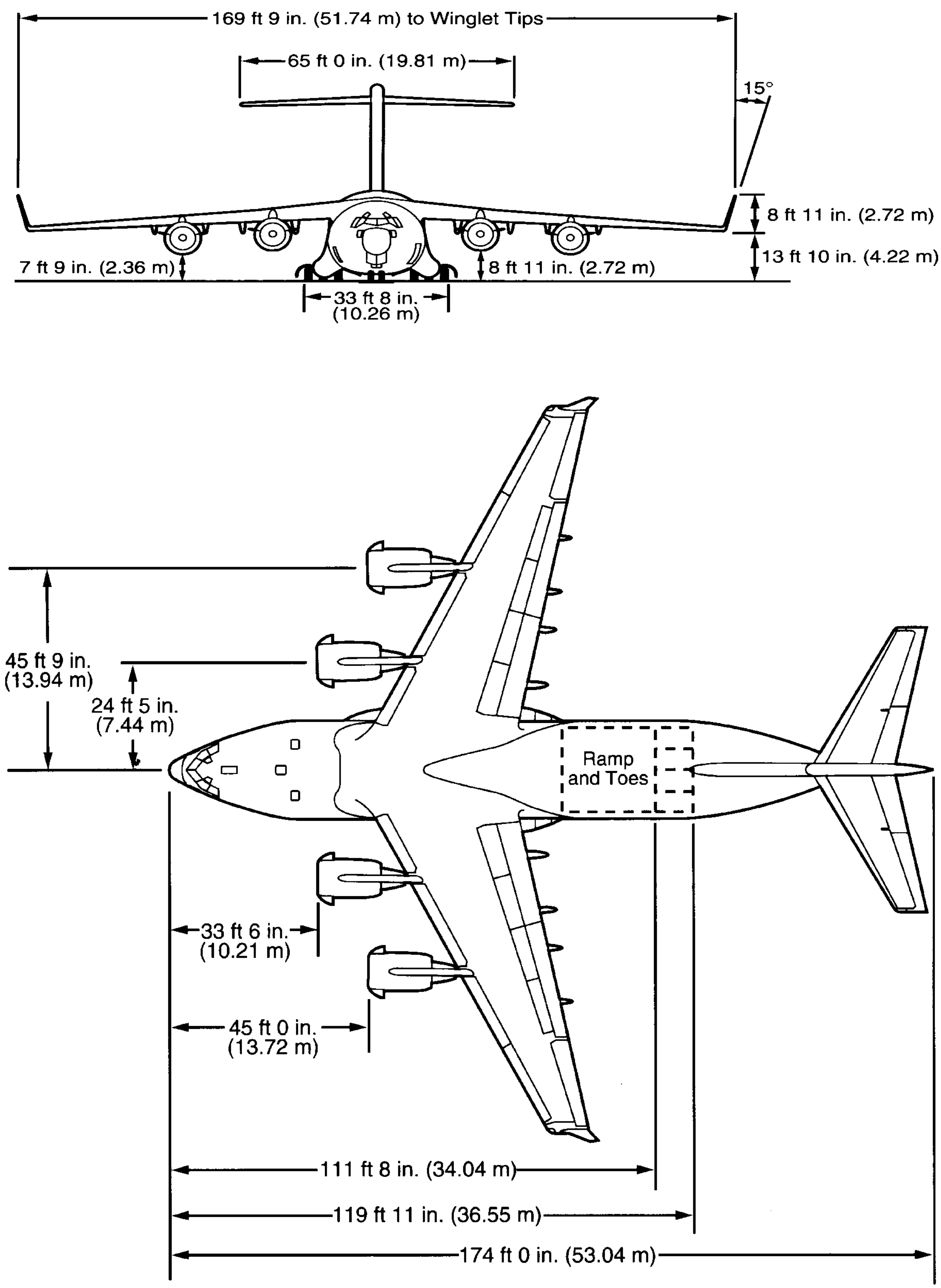


Figure 2.1. Horizontal and Vertical Aircraft Dimensions

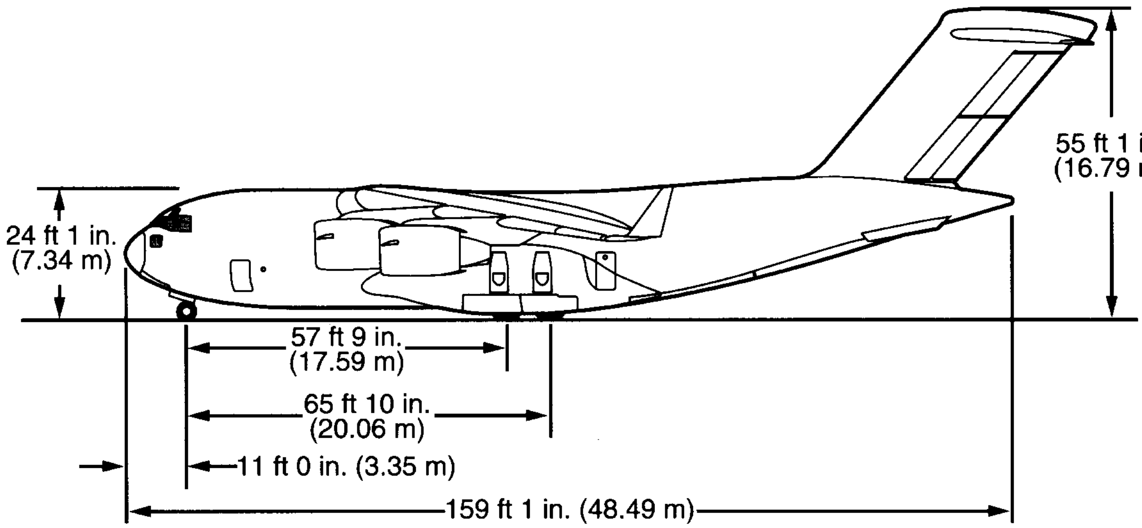


Figure 2.1. Horizontal and Vertical Aircraft Dimensions (Continued)

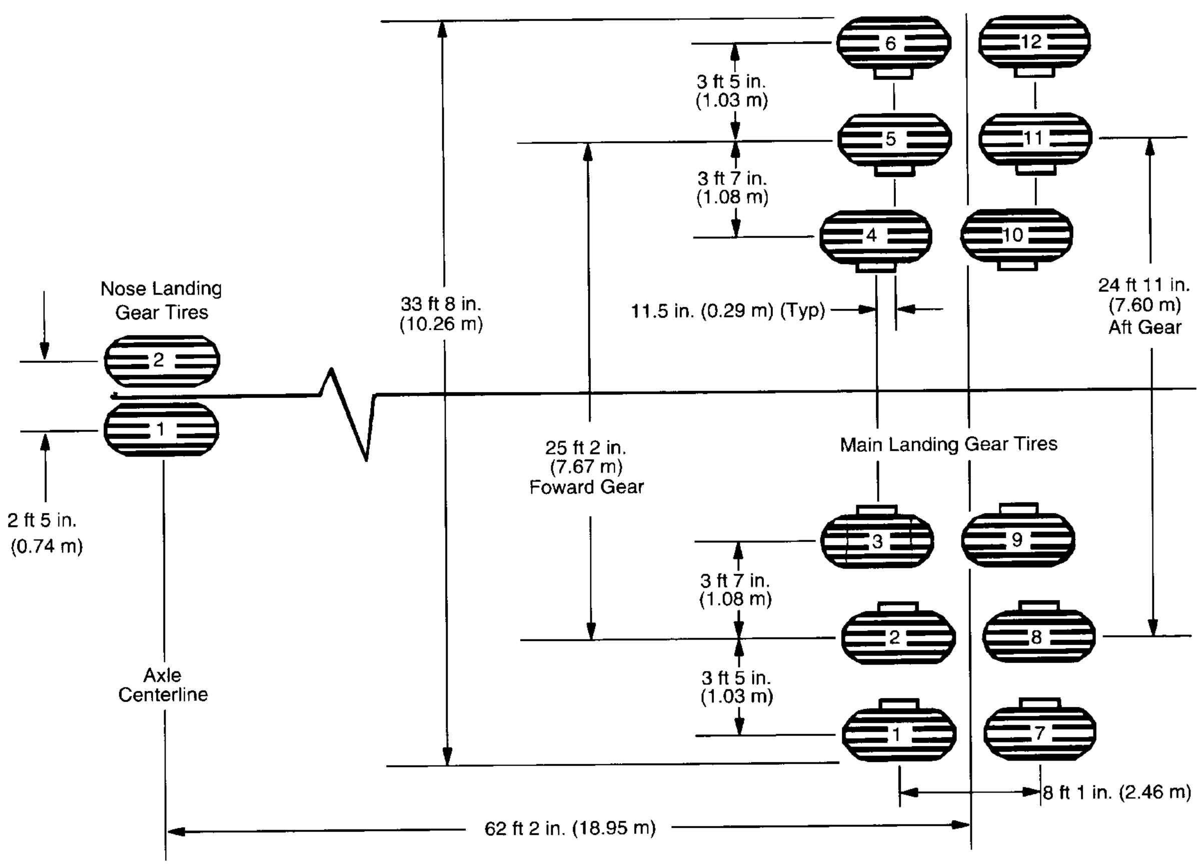


Figure 2.2. Landing Gear Dimensions

(15 October 1997)

Aircraft Classification Numbers. The International Civil Aviation Organization has developed and adopted a standardized method of reporting pavement strength for conventional rigid and flexible pavements. This procedure is known as the Aircraft Classification Number/Pavement Classification Number (ACN/PCN). The ACN is a number that expresses the effect an aircraft will have on a pavement. The PCN is a number that expresses the capability of a pavement to support aircraft operations. ACNs for the C-17 for maximum gross weight, maximum operating and minimum operating weight for contingency and training operations on semi-prepared airfields are shown in the following table. Figure 2.3 shows ACN values for any C-17 weight. A more detailed discussion of the ACN/PCN procedure and CAN values for the C-27 and C-130 are contained in Appendix C.

Aircraft Classification Numbers
Subgrade Strength

Aircraft Wt. (Kips)	High CBR 13 (A)	Medium CBR =9-13(B)	Low CBR=4-8(C)	Ultra Low CBR 4(D)
586	68	75	85	109
447	47	53	60	77
279	21	28	30	37

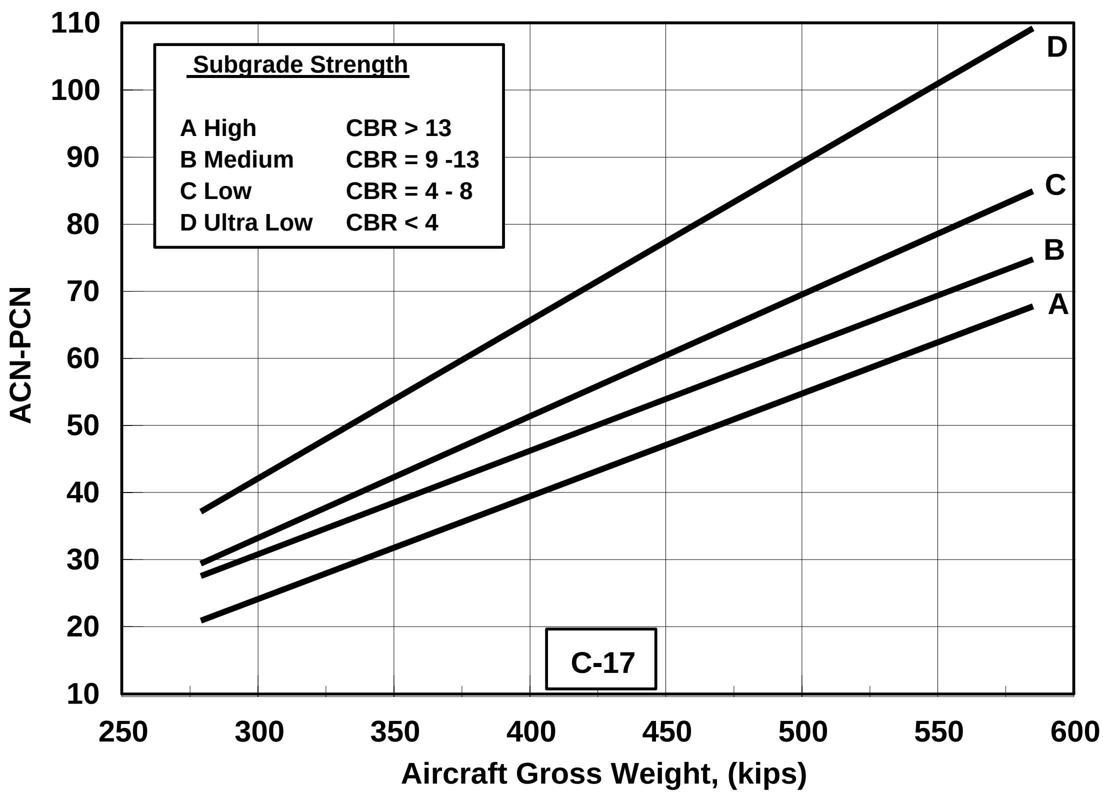


Figure 2.3. Aircraft Classification Number for C-17 for Contingency Operations

Turning Criteria. Experience has shown that tight turns on semi-prepared airfields damage the surface and produce foreign object damage. Therefore, star turns are not recommended. The criteria in figure 2.4 are the basis for the hammerhead dimensions contained in this document.

Type Turn	Steering Input	Effective Turn Angle	Tire Slippage Angle	Minimum Taxiing Radii (Feet) X	Y	A	R3	R4	R5	R6
Optimal	65(max)	52	8	62	48	146	81	136	88	129
Limit	60	53	12	62	47	143	80	134	87	128

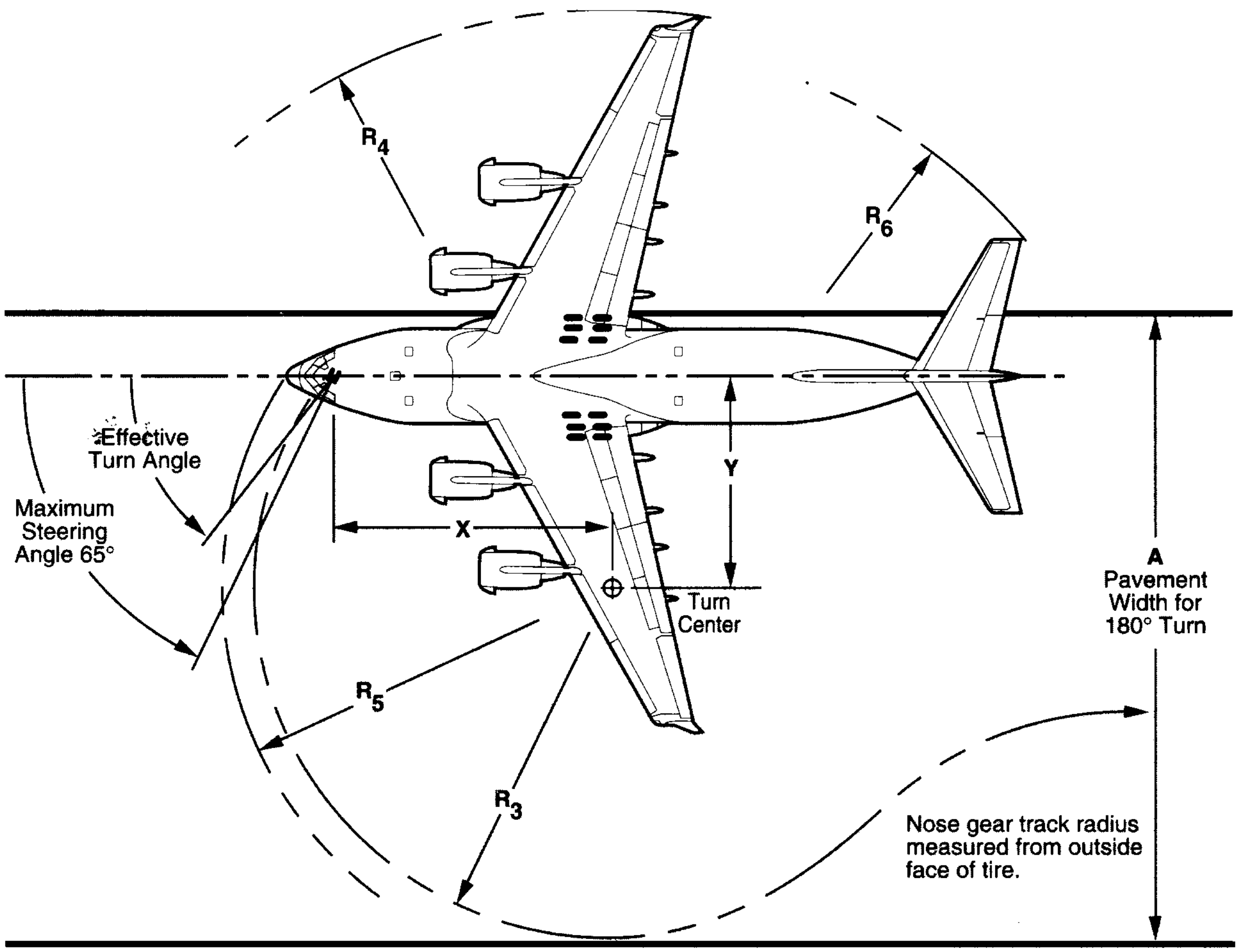


Figure 2.4. Turning Criteria

Section 3. Dimensional Criteria

3.1. Contents. This section presents design considerations unique for C-17 contingency airfields. This criteria is given as a supplement to the criteria given in AFJPAM 32-8013/FM 5-430-00-2, Planning and Design of Roads, Airfields and Heliports. With introduction of the C-17 came the requirement to validate existing design criteria or develop new criteria as required to accommodate contingency operations on semi-prepared runway surfaces.

3.2. Runway and Overrun Descriptions. Tables 3.1 and 3.2 provide dimensional criteria for layout and design of assault landing zones.

3.2.1. Length. For a semi-prepared runway located between sea level and 6,000 feet pressure altitude, the minimum length requirement for C-17 operations is 3,500 feet with 300-foot overruns on each end. This length requirement, based upon an RCR of 20, assumes an ambient temperature equal Standard (1962) plus 31 ºF, and a landing gross weight of 447,000 pounds. Based upon these same temperature and weight assumptions, the runway length will vary with different RCRs as follows:

RCR	Pressure Altitude (feet)	Runway Length (feet)
20	0 -6,000	3,500
16	0 - 2,000	3,500
	2,001 - 5,000	4,000
	5,001 - 6,000	4,500
12	0 - 2,000	4,000
	2,001 - 5,000	4,500
	5,001 - 6,000	5,000
8	0 - 3,000	5,000
	3,001 - 5,000	5,500
	5,001 - 6,000	6,000

Note: The runway lengths **do not** include under/overruns.

3.2.2. Width. The widths of these landing surfaces must be sufficient to protect the aircraft landing gear and the engines. Table 3.1 provides the minimum runway width.

3.2.3. Longitudinal Gradients of Operational Surfaces. Gradient constraints are based upon reverse aircraft operations conducted on hard surfaces. Caution should be used when backing aircraft on soft soil conditions, at any gradient.

3.2.4. Shoulders. Shoulders are graded and cleared of obstacles and slope downward away from the runway where practical to facilitate drainage.

Table 3.1. Runways for C-17 Contingency Airfields

m o.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
.	Length	Minimum 1,067 m [3,500 ft] See Remarks	Runway length of 3,500 ft required for locations between sea level and 6,000 pressure altitude, based upon an RCR of 20, an ambient temperature of Standard (1962) +31 ºF, and landing gross weight of 447,000 lbs. See paragraph 3.2.1 for runway requirements based upon different RCRs.
.	Width	27.5 m [90 ft]	See Note 1.
.	Width of Shoulders	3 m [10 ft]	Remove all tree stumps and loose rocks in shoulder areas. Shoulders should be stabilized to prevent erosion by jet blast. Where adequate sod cove cannot be established, the shoulders should be chemically stabilized.
.	Longitudinal Grades of Runway and Shoulders	Maximum 3%	Hold to minimum practicable. Grades may be both positive and negative but must not exceed the limit specified.
5.	Longitudinal Runway Grade Change	Max 1.5% per 60 m [200 ft]	Longitudinal grade changes cannot occur within 150 m [500 feet] of runway ends. Minimum distance between grade changes is 122 m (400 ft).
i.	Transverse Grade of Semi-Prepared Runway	0.5 -3.0%	Transverse grades should slope down from the runwa centerline. The intent of the transverse grade limit is t provide adequate cross slope to facilitate drainage wit adversely affecting aircraft operations.
'.	Transverse Grade of Runway Shoulder	1.5% Minimum to 5.0% Maximum	
3.	Lateral Clear Area	10.5 m [35 ft]	Remove or embed rocks larger than 6 inches in diame Cut tree stumps to within 6 inches of the ground. Rem vegetation (excluding grass) to within 6 inches of grou
).	Transverse Grade of Lateral Clear Area	2.0% Minimum to 5.0% Maximum	Grades may slope up or down to provide drainage. Exception: Essential drainage ditches may be sloped to 10% in the primary surface area and clear zones. D not locate these ditches within 27.5 meters [90 feet] o the runway centerline. Such ditches should be essent parallel with the runway

Note 1. For C-17 airfields without parallel taxiways, provide a method for turning around at both ends of the usable surface. The turnarounds should be 55 m [180 ft] long and 50 m [165 feet] wide (including the runway/overrun width), with 45º fillets and be constructed to same structural and gradient standards as the runway/overrun. The aircraft must be positioned within ten feet of the runway edge prior to initiating this turn. Provide an expanded hammerhead or taxiways and aprons if the airfield maximum-on-ground requirement is greater than one.

Table 3.2. Overruns for C-17 Contingency Airfields

Item No.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
1.	Overrun Length	91.5 m [300 ft]	The overruns must be constructed to the same standards as the runway. Overruns for mat surfaced runways must also be constructed with mat.
2.	Overrun Width	27.5 m [90 ft]	
3.	Longitudinal Grade of Overruns	See Remarks	The grade must be constant and is the same as the last 150 m [500 ft] of the runway end.
4.	Transverse Grade of Overruns	See Remarks	Same as runway end. Grades should slope downward from overrun centerline.

3.3. Clear Zones, Accident Potential Zones, and Imaginary Surfaces. The clearance and grade requirements for assault landing zones are established to provide a reasonable level of safety at forward operating locations during contingencies. Criteria for clear zones, and imaginary surfaces are in Tables 3.3, 3.4, and 3.5, respectively. These surfaces are displayed in Figures 3.1 through 3.4.

3.4. Taxiways. The widths and turning radius are similar to that for class A and B fixed-wing airfields, but the clearances and grades are less stringent. Criteria for taxiways are in Table 3.6, and illustrated in Figure 3.4.

3.5. Aprons. The clearance, as well as the longitudinal and transverse grades for aprons are in Table 3.7.

3.6. Airfield Marking. Schemes for night and day marking of airfields are illustrated in Figures 3.5 and 3.6.

3.6.1. The Visual Assault Zone Marker Panel (VAMP). The VAMP comes in three different configurations, the low, medium and the high velocity model; the low velocity version to withstand sustained wind blasts up to 150 miles per hour, the medium velocity version to withstand wind blasts from 150 to 200 MPH and the high velocity version to withstand winds of 200 MPH and greater. We have listed the differences among the three models (by design) below. A drawing of the VAMP is depicted in Figure 3.7.

Table 3.3. Runway End Clear Zone for C-17 Contingency Airfields

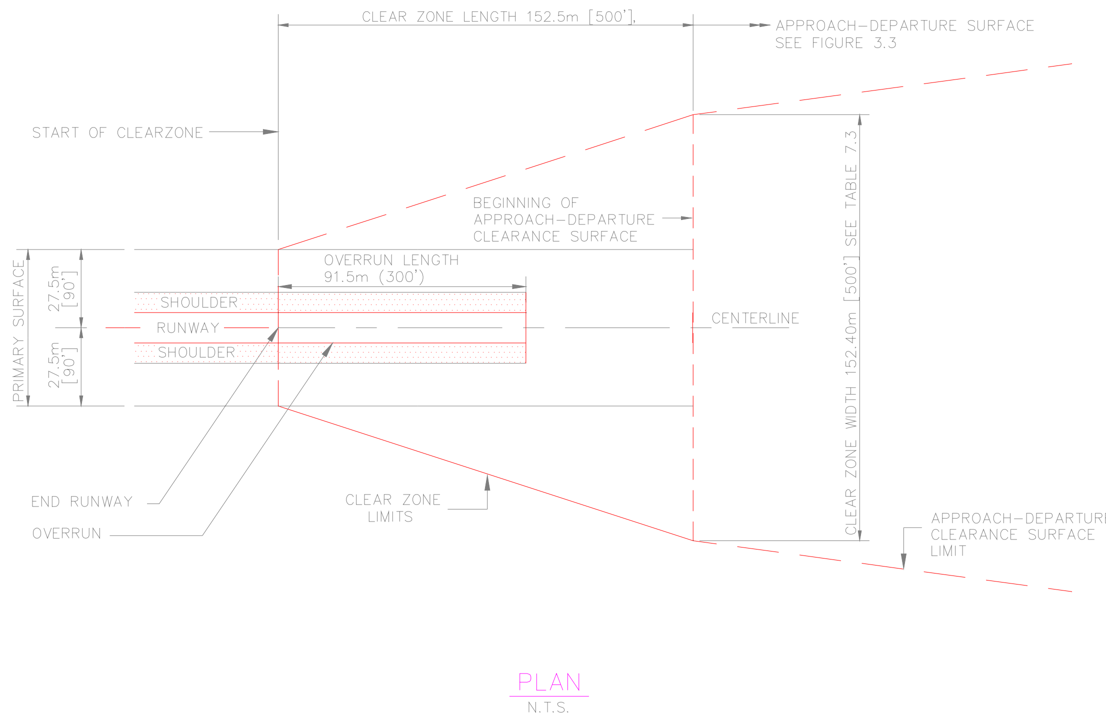
Item No.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
1.	Length	152.5 m [500 ft]	Measured along the extended runway centerline. Begins at the runway threshold.
2.	Width at Inner Edge	55 m [180 ft]	
3.	Width at Outer Edge	152.5 m [500 ft]	
4.	Longitudinal and Transverse Grade of Surface	Maximum 5.0%	Grades are exclusive for clear zone and are not part of the overrun but are shaped into the overrun grade. See Table 3.2, Item 3 for additional information. Grades may slope up or down to provide drainage. Exception: Essential drainage ditches may be sloped up to 10% in the primary surface area and clear zones. Do not locate these ditches within 27.5 meters [90 feet] of a runway centerline. Such ditches should be essentially parallel with the runway. Remove or embed rocks larger than 2 inches in diameter. Cut tree stumps, brush, and other vegetation (excluding grass) to within 2 inches of the ground.

Table 3.4. Accident Potential Zones (APZ) for C-17 Contingency Airfields

Item No.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
1.	APZ 1 Length	762 m [2,500 ft]	Limit where possible the following within the APZ: Actions that release any substances into the air that would impair visibility or otherwise interfere with operating aircraft, such as steam, dust, and smoke. Actions that produce electrical emissions which would interfere with aircraft and/or communications or navigational aid systems. Actions that produce light emissions, direct or indirect (reflective), that might interfere with pilot vision. Items that unnecessarily attract birds or waterfowl, such as sanitary landfills, feeding stations, or certain types of crops or vegetation. Explosive facilities or activities. Troop concentrations, such as housing areas, dining or medical facilities, and recreational fields that include spectators.
2.	APZ 1 Width	152 m [500 ft]	

Table 3.5. Imaginary Surfaces for C-17 Contingency Airfields

Item No.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
1.	Primary Surface Length	Runway length plus 305 m [1,000 ft]	Centered on the runway. (Includes lengths of clear zones.)
2.	Primary Surface Width	55 m [180 ft]	Centered on the runway.
3.	Transverse Grades within Primary Surface (in direction of surface drainage)	Minimum 2.0% Maximum 5.0%	Transverse grades may slope up or down to provide drainage ditches. Centerline of drainage ditches must be established away from runway shoulders to prevent water from backing up onto the shoulder area. Exception: Essential drainage ditches may be sloped up to 10% in the primary surface area and clear zones. Do not locate these ditches within 27.5 meters [90 feet] of an Assault Landing Zone centerline. Such ditches should be essentially parallel with the runway.
4.	Lateral Safety Zone: Inner Edge	27.5 m [90 ft]	Measured from the runway centerline. Coincident with the lateral edges of the primary surface.
5.	Lateral Safety Zone: Outer Edge	42.5 [140 ft] from the runway centerline	Connects the primary and the approach-departure clearance surfaces.
6.	Lateral Safety Zone -- Slope	5H:1V	
7.	Horizontal Surface	No Requirement	
8.	Approach-Departure Clearance Surface -- Inner Edge	152.5 m [500 ft]	Measured from runway end.
9.	Width at Inner Edge.	152.5 m [500 ft]	
10.	Slope	20H:1V	Remains constant throughout length.
11.	Slope Length	Minimum 3,200 m [10,500 ft]	The desired slope length is 9,733 m [32,000 ft]
12.	Width at Outer Edge	762.00 m [2,500 ft] at 3200 m [10,500 ft] from inner edge	Width of approach-departure clearance surface is constant from 3,200 m [10,500 ft] to 9,753 [32,000 ft] from the inner edge



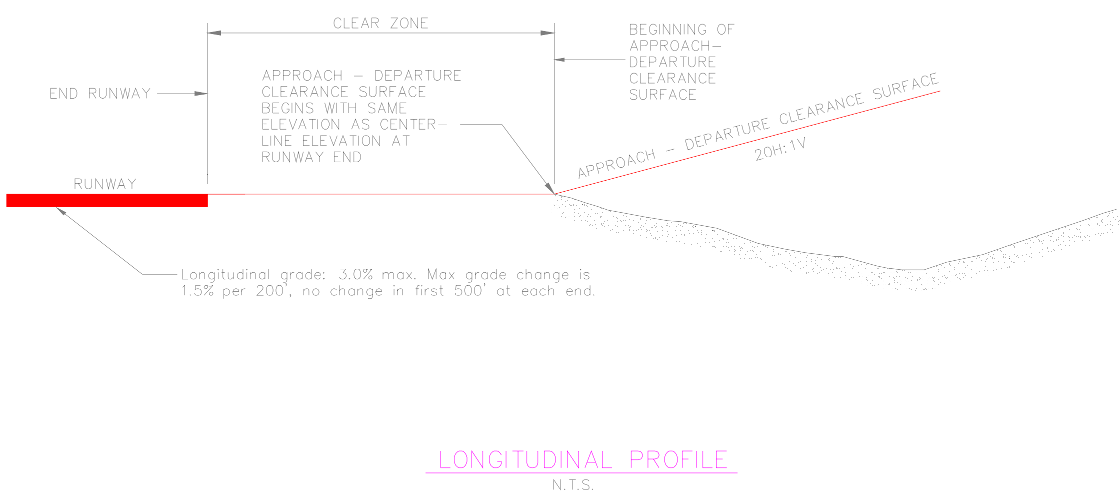


Figure 3.1. Primary C-17 Contingency Airfield Surface End Details

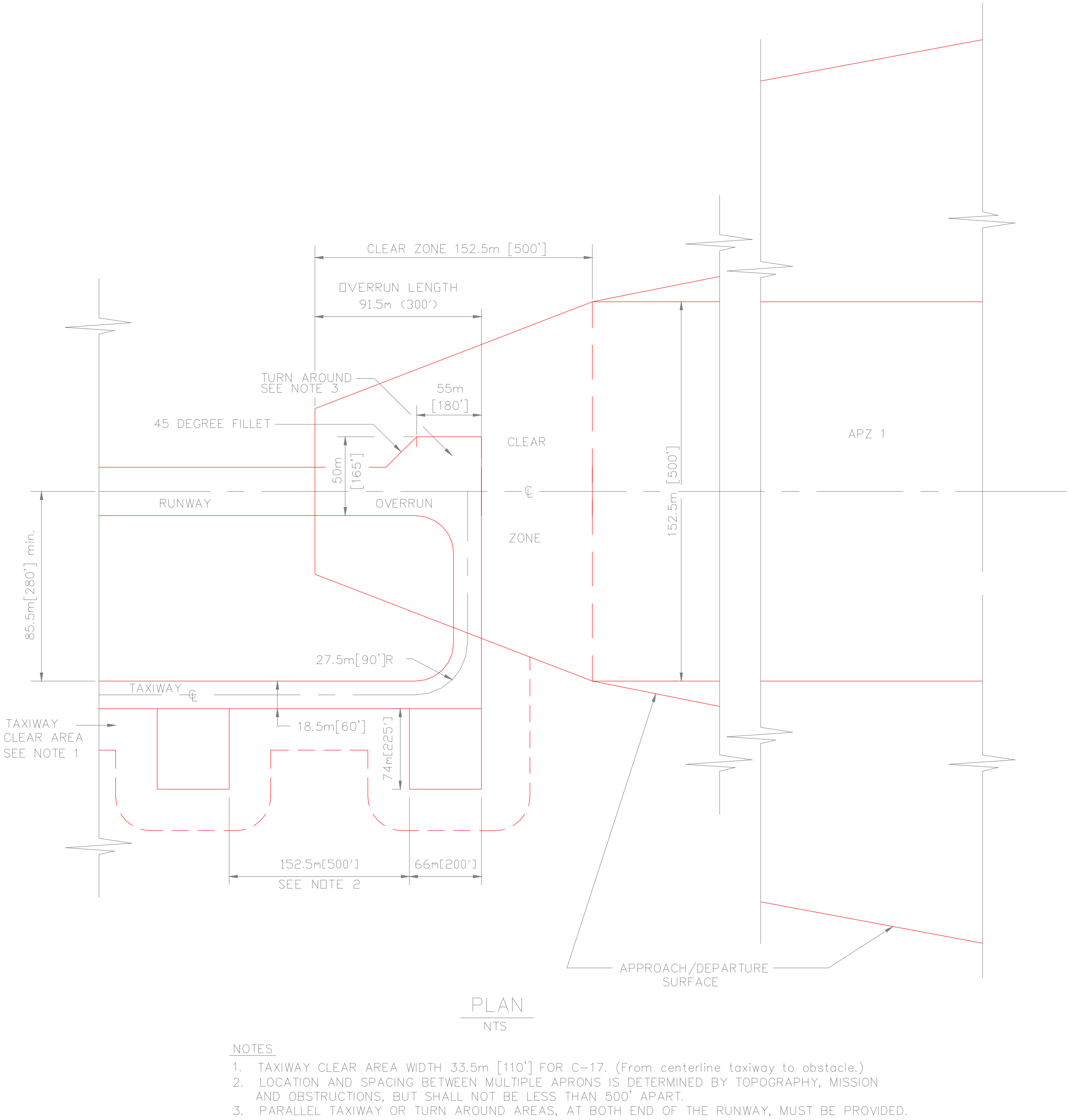


Figure 3.2. C-17 Contingency Airfield Detail

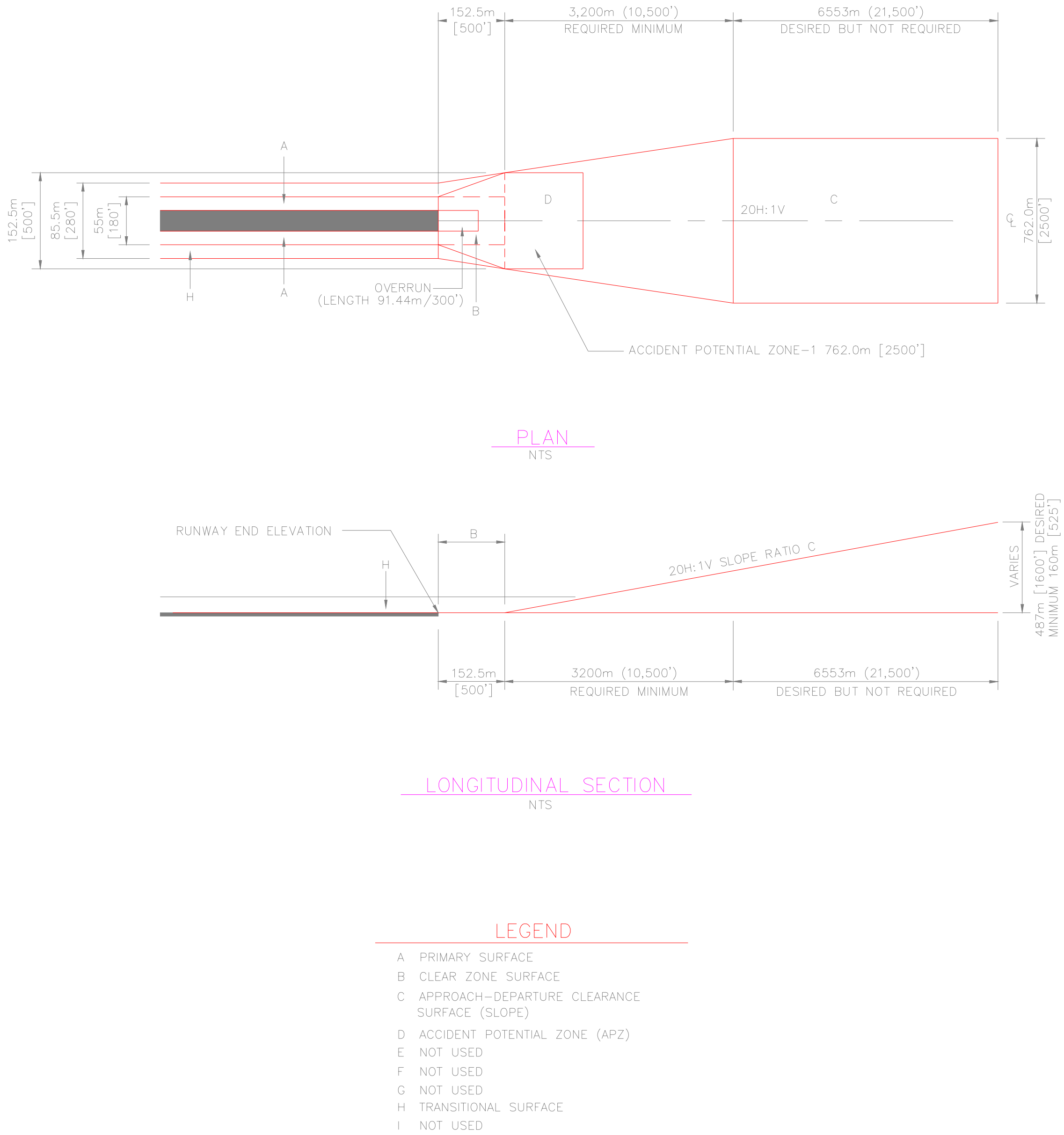


Figure 3.3. C-17 Contingency Airfield Runway Imaginary Surfaces

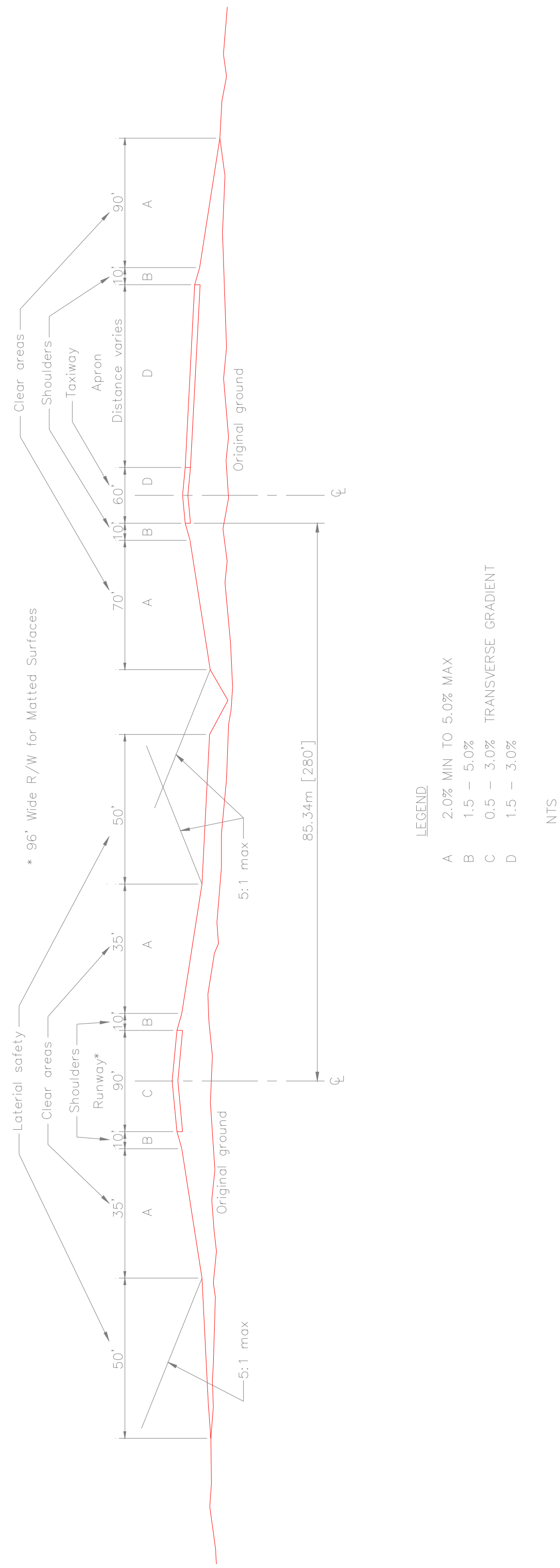


Figure 3.4. C-17 Contingency Airfield Runway, Taxiway, and Apron Section

Table 3.6. Taxiways for C-17 Contingency Airfields

Item No.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
1.	Width	18 m [60 ft]	
2.	Turning Radii	27.5 m [90 ft]	
3.	Shoulder Width	3 m [10 ft]	Shoulders should be stabilized to prevent erosion by jet blast. Where adequate sod cover cannot be established, the shoulders should be chemically stabilized for blast protection. Remove all tree stumps and loose rocks.
4.	Longitudinal Grade	Maximum 3.0%	Hold to minimum practicable. Grades may be both positive and negative.
5.	Rate of Longitudinal Grade Change	Maximum 2.0% per 30 meters [100 feet]	The minimum distance between two successive points of intersection (PI) is 60 meters [200 feet]. Changes are to be accomplished by means of a vertical curve.
6.	Transverse Grade of Taxiway	0.5% to 3.0%	Transverse grades are to slope down from the taxiway centerline. The intent of the transverse grade limitation is to provide adequate cross slope to facilitate drainage without adversely affecting aircraft operations. The surfaces should slope so that the centerline of the taxiway is crowned.
7.	Transverse Grade of Taxiway Shoulder	1.5% to 5.0%	Aircraft are not permitted to use shoulders on AM-2 airfields due to horizontal and vertical load devices connected to the mat edges.
8.	Runway Clearance	85.5 m [280 ft]	Measured from the runway centerline to near edge of the taxiway.
9.	Clearance to Fixed or Mobile Obstacles	33.5 m [110 ft]	Measured from the taxiway centerline.
10.	Taxiway Clear Area -- Width	21.5 m [70 ft]	Remove or embed rocks larger than 6 inches in diameter. Cut tree stumps, brush, and other vegetation (excluding grass) to within 6 inches of the ground.
11.	Taxiway Clear Area -- Grade	Maximum 5.0%	Transverse grades may slope up or down to provide drainage ditches. Centerline of drainage ditches must be established away from taxiway shoulders to prevent water from backing up on to the shoulder area. Exception: Essential drainage ditches may be sloped up to 10%.

Table 3.7. Apron for C-17 Contingency Airfields

Item No.	Item Description	Contingency Airfield (Semi-Prepared and AM-2)	Remarks
1.	Apron size		Sized to accommodate mission
2.	Apron Grades in the Direction of Drainage	1.5 to 3.0%	
3.	Width of Apron Shoulder	3 m [10 ft]	Apron shoulders should be stabilized to prevent erosion by jet blast. Where adequate sod cover cannot be established, the shoulders should be chemically stabilized for blast protection.
4.	Transverse Grade of Shoulder away from the Apron Edge	1.5 to 5.0%	Apron shoulder should be graded to carry storm water away from the apron. In shoulder areas, remove all tree stumps and loose rocks. Aircraft are not permitted to use shoulders on AM-2 airfields due to horizontal and vertical load devices connected to the mat edges.
5.	Clearance from Edge of Apron to Fixed or Mobile Obstacles	30 m [100 ft]	

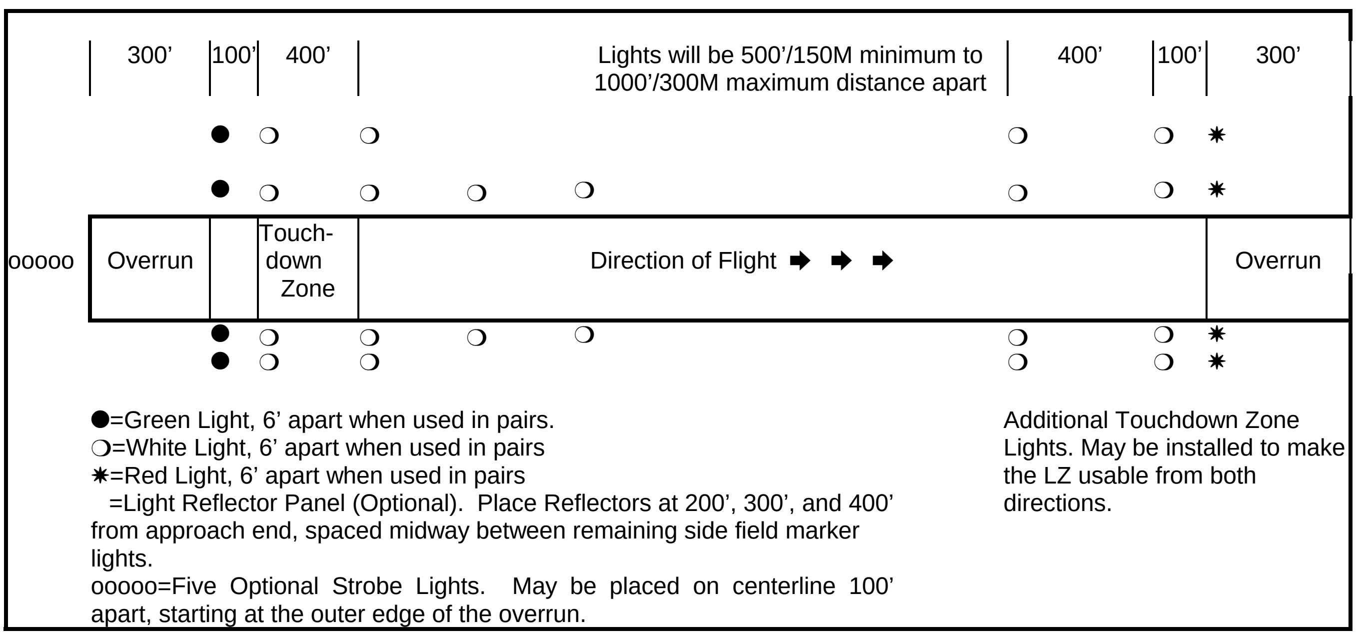


Figure 3.5 Airfield Marking Pattern (Night)

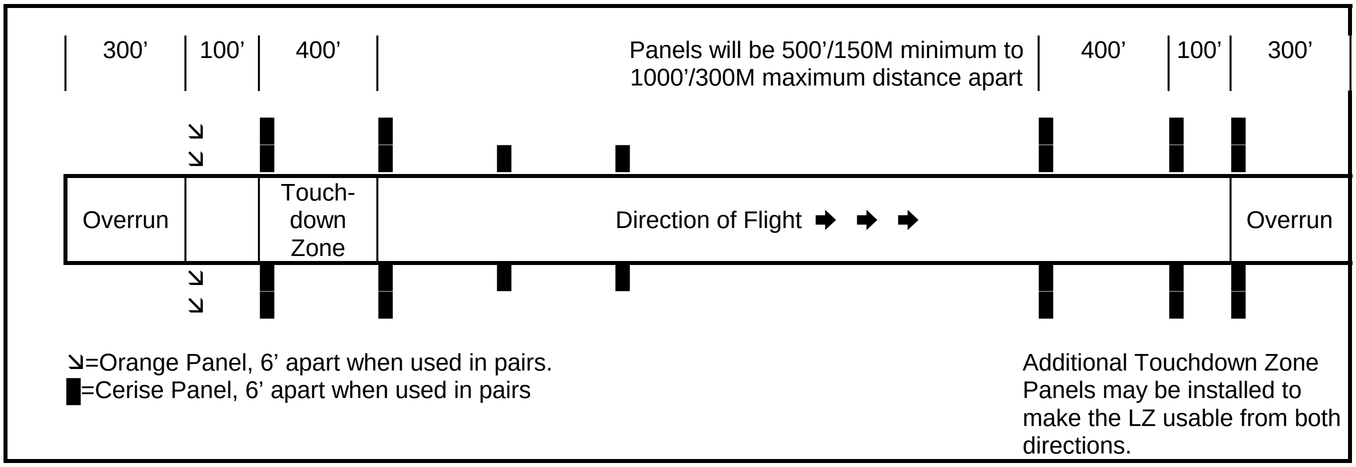


Figure 3.6 Airfield Marking Pattern (Day)

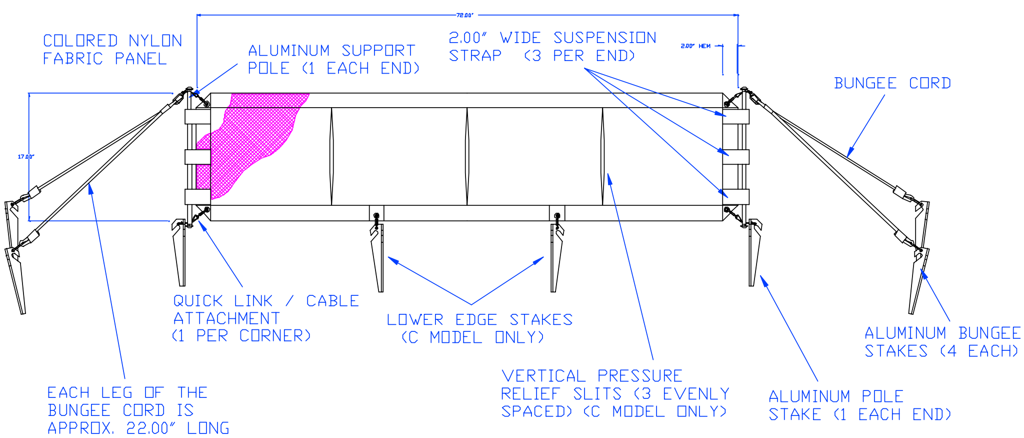


Figure 3.7. Visual Assault Zone Marker Panel (VAMP)

3.6.1.1. VAMP (C Model) - TACTEC Part Number: AMS-0004-C-00001will be used for C-17 operations. The ‘C’ Model is the high velocity VAMP designed for use with aircraft that generate a maximum take-off blast (jet or prop) greater than 200 mph. This VAMP is constructed of a cerise- and/or orange-colored (420 denier nylon) fabric panel 17 inches high by 72 inches long. This panel is reinforced around its entire outer edge by a two-inch-wide (1000# test) nylon webbing that is sewn into the colored panel material. Three 2-inch webbing loops are evenly spaced and sewn to each of the 17-inch sides. Additionally, there are two 20-inch webbing stiffeners evenly spaced along the bottom edge of the fabric panel. There is a 0.3125-inch inside diameter (ID) brass-coated steel grommet pressed into each of the two webbing stiffeners. There are three vertical slits, evenly spaced, sewn into the panel. This allows for air pressure relief while under maximum stress loads. There is a 0.3125-inch inside diameter (ID) brass-coated steel grommet pressed into each corner of the panel. The panel is supported and suspended by two 19-inch long by 0.500-inch outside diameter (OD) aluminum poles. The poles are constructed of hollow aluminum tubing, reinforced by a round head, 0.375 inch by 2-inch carriage bolt inserted into each end of the pole. The poles are inserted through the 2-inch webbing loops at each end of the panel. The panel is then attached to the poles by a 0.125-inch machine-crimped steel cable configuration. Each corner of the 17-inch side(s) is attached to each end of the aluminum support pole(s) by this method. Attached to the top end of each pole is a bungee system that is made up of 10-millimeter, double-nylon-coated bungee cord. Each of the two bungee systems consists of a single 52-inch long (unstretched) piece of bungee cord. This cord is folded and crimped in the middle forming a loop, and at each of the two ends. The three loops that are formed by this crimping are fitted with three, 2-inch long, 0.187-inch diameter quick-link connectors. The connector at the middle of the bungee is attached to the top of the aluminum pole. A 9-inch aluminum tent stake is attached to each of the four bungee ends, to the bottom of each pole, and to each of the two stiffeners (at the bottom edge of the panel).

3.6.1.4. Additional Equipment. In addition to the 6 aluminum tent stakes (common to all VAMP models) there are six 8-inch (eight 8-inch for the VAMP - C Model) steel spikes attached by stainless steel safety cable. These spikes are much stronger than the aluminum stakes and they allow for the use of the VAMP on extreme surface conditions such as asphalt.

Section 4. Structural Design Criteria

4.1. Introduction. This section presents the procedures for the structural design of semi-prepared airfields for the C-17 aircraft. This criteria is submitted as a supplement to that given in AFJPAM 32-8013/FM 5-430-00-2, Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations. The introduction of the C-17 resulted in the requirement to validate existing design criteria or develop new criteria for contingency operations on semi-prepared runways. Semi-prepared airfields include unsurfaced, aggregate-surfaced, and matted airfields. The criteria presented provides guidance for designing unsurfaced, aggregate-surfaced, and AM-2 mat-surfaced airfields for the operation of the C-17 aircraft.

4.2. Site Investigation. The site investigation for input to the structural design of a semi-prepared airfield is required to determine the in-place material properties and the properties of the materials that are available for use in constructing a contingency airfield. If an existing airfield is to be used, the evaluation portion of this document (Appendix C)should be used for investigating the capability of the airfield to support C-17 aircraft operations. If an existing airfield is not capable of supporting operations of the C-17 aircraft, the airfield will need to be upgraded or repairs and maintenance will be required periodically during the mission. If it is determined that an existing airfield will be upgraded, the design portion of this document should be used and the material characteristics of the existing airfield and available materials for upgrading will be required for input to the design procedure. Knowledge of the current field condition at a site to be used for a contingency airfield is important (FM 5-430-00-2/AFJPAM 32-8013, Vol II). A proper description of the field condition at a proposed site includes the following elements:

- ground cover (vegetation).
- natural slopes.
- soil types (classification).
- soil density.
- moisture content.
- soil consistency (soft or hard).
- existing drainage.
- natural soil strength (in terms of California Bearing Ratio).

The information listed above is needed to determine the construction effort required to provide an airfield capable of supporting the design number of operations of the C-17 aircraft.

4.3. Base, Subbase, and Subgrade. A semi-prepared pavement structure typically consists of three layers, the existing subgrade, a subbase, and a base course. A semi-prepared airfield may or may not have a subbase or a base. If the existing material (the subgrade) is determined to be capable of supporting aircraft operations, no subbase or base will be required. A subbase may consist of subbase material and a select material if a select material is available and of better quality than the subgrade (see FM 5-430-00-1/AFPAM 32-8013, Vol 1, Chapter 5). The subgrade, potential subbase and potential base materials need to be identified according to the Unified Soil Classification

System (USCS). The evaluation portion of this document details the USCS and field procedures for identifying soils and categorizing them according to the USCS.

4.4. Soil Strength. The strength of the existing soil and any layers that will be constructed above it are important parameters that are input to the design procedure. For semi-prepared pavements, the parameter used for indicating the strength of the layers is the California Bearing Ratio (CBR). The CBR is a measure of the shearing resistance or strength of the soil. The evaluation portion of this document discusses the tools and procedures for quickly obtaining an estimate of the CBR of in-place soils. For soils or materials that are to be placed (i.e. excavated, hauled, placed and compacted) it will be necessary to determine the CBR that will be obtainable. A moisture-density relationship (proctor curve) with accompanying laboratory CBR values is preferred for determining the CBR obtainable in the field and for specifying moisture and density requirements during construction. The CBR value of a material to be placed may be significantly different than the in-place CBR of the material. Some soils loose strength with remolding (see Chap 8 FM 5-410). Other soils if properly placed can achieve CBR values greater than existed naturally. This is accomplished by compacting the soil at or near optimum moisture content with an appropriate compactive effort to obtain near maximum density. If maximum density is not achieved, a reduction in available performance results with a reduction in the number of aircraft operations the airfield can support before failure occurs. Appendix C provides information on ranges of CBR that can be expected for different soil types. A conservative estimate of CBR based on the material type may be used for preliminary design. During construction, the actual CBR can be measured with the dynamic cone penetrometer (DCP), and the design of the semi-prepared pavement can be adjusted as necessary. It should be noted that the CBR may change with time as the material becomes saturated. Saturation of the material usually results in a reduction in the CBR, this fact should be accounted for in the design of the airfield. Soaked laboratory CBR values provide a good indication of the reduction in the CBR that may be expected. Otherwise, conservative values based on the material type and the CBR determined in the field should be used for design. The gradation portion of this document also provides an indication of the CBR that may be expected for materials meeting gradation and compaction requirements.

4.5. Soil Behavior. Soil is compacted to improve its load-carrying capability (5-430-00-2/AFJPAM 32-8013, Vol II).   The compaction of soil reduces its natural variability providing a more uniform structure for operating aircraft. Compaction also reduces the soils permeability and susceptibility to erosion. Stabilization of soils can be used to improve the strength of the soil or to reduce the effects of plasticity and high liquid limits. Stabilizing can also provide dustproofing and waterproofing. Stabilization is addressed in Section 4.8 of this document.

4.6. Gradation Requirements. The recommended gradation requirements and design CBR values for the subbase and select material (FM 5-430-00-1/AFPAM 32-8013, Vol 1) are shown in Table 4.1. Select material is used when an additional thickness above the subgrade is required and can be achieved with a more readily available material than the subbase or base material.

Table 4.1. Recommended Maximum Permissible Value of Gradation and Atterberg Limit Requirements in Subbases and Select Materials

Maximum Permissible Value						
			Gradation requirements % passing		Atterberg Limits	
Material	Maximum design CBR	Size in inches	No. 10	No.200	LL*	PI*
Subbase	50	2	50	15	25	5
Subbase	40	2	80	15	25	5
Subbase	30	2	100	15	25	5
Select Material	20	3	---	---	35	12

*Determination of these values will be made according to ASTM D4318.

The recommended gradation requirements for base course materials (FM 5-430-00-1/AFPAM 32-8013, Vol I) are shown in Table 4.2. The base course should also meet the plastic and liquid limit requirements set for the subbase material as shown in Table 4.1. A material with a liquid limit greater than 25 or a plasticity index greater than 5 should not be used as a base course. The strengths in terms of a design CBR that may be expected of the base course material (FM 5-430-001/AFPAM 32-8013, Vol 1), if it meets the gradation and compaction requirements (Table 4.4), are shown in Table 4.3.

Table 4.2. Recommended Gradation for Crushed Rock, Slag, Uncrushed Sand and Gravel Aggregates for Base Courses

	Percent Passing Each Sieve (Square Openings) by Weight			
Sieve Designations	Maximum Aggregate Size			
	2 inch	1 ½ inch	1 inch	1-inch sand clay
2 inch	100	---	---	---
1 ½ inch	70-100	100	---	---
1 inch	55-85	75-100	100	100
¾ inch	50-80	60-90	70-100	---
3/8 inch	30-60	45-75	50-80	---
No. 4	20-50	30-60	35-65	---
No. 10	15-40	20-50	20-50	65-90
No. 40	5-25	10-30	15-30	33-70
No. 200	0-10	5-15	5-15	8-25

Table 4.3. CBR Ratings for Base-Course Materials

Material Type	Design CBR
Graded, crushed aggregate	100
Water-bound macadam	100
Dry-bound macadam	100
Lime rock	80
Soil cement	80
Sand shell or shell	80

4.7. Compaction Requirements. The recommended compaction requirements for the base, subbase, select material and subgrade are shown in Table 4.4. In general, the top six inches of the subgrade is compacted to density requirements indicated in Table 4.4.

Table 4.4. Recommended Compaction Requirements for Semi-Prepared Airfields

Material	CBR	Percent Compaction Required	
		Cohesive	Cohesionless
Base course	80-100	NA	100-105
Subbase	20-50	NA	100-105
Select material & Subgrade	<20	90 - 95	95-100

Notes:

1. A cohesive soil has a PI > 5; a cohesionless soil is one with a PI ≤ 5.
2. Cohesive soils are Not Applicable (NA) for use as a base or subbase.
3. Percent compaction is a percent of the maximum density at CE 55.
4. The minimum compacted layer thickness is 6 inches for an airfield.
5. Select material will have a CBR<20 and >subgrade CBR.

4.8. Stabilization. There are two major types of stabilizing procedures, mechanical and chemical. Mechanical stabilization involves any of the following: compaction, blending of aggregates, or adding a bitumen. Chemical stabilization involves the addition of material, such as lime, cement, or fly-ash, that chemically reacts with the soil or itself to improve properties of the soil. (See FM 5-410, Military Soils Engineering, for further information). As discussed previously, stabilization may be used to increase the strength, provide dust proofing, reduce the maintenance effort required for continued operations, and increase performance by improving the shearing resistance during operations. Stabilization of a contingency airfield is appropriate when time and logistics allow for it to be accomplished and the mission requirements are substantial enough to require it. Functions of stabilization for traffic areas and non-traffic areas of the airfield are listed in Table 12-5, pp. 12-19 (see FM 5-430-00-2/AFJPAM 32-8013, Vol. II). Table 12-6, pp. 12-21 (see FM 5-430-00-2/AFJPAM 32-8013, Vol. II) provides a table listing dust-control and waterproofing materials that can be used and their appropriate application.

4.8.1. Stabilization Recommendations. For training airfields, stabilization of the surfacing material is desirable. When stabilizing the airfield surface to improve the strength of the existing material, cement and/or lime generally will be the most appropriate stabilizing agent to use. Bituminous materials are appropriate for stabilizing coarse-grained materials. However, to provide a quality layer, the bituminous stabilized material should be mixed in a plant -- not mixed in-place. It is very difficult to obtain the mixing, compaction, and grade control required using in-place mixing of bituminous materials. Army TM 5-822-14/Air Force AFJMAN 32-1019, *Soil Stabilization for Pavements*, provides detailed guidance on design and construction of stabilized layers. The following paragraphs provide general design and construction guidance.

4.8.2. General Design Guidance. The thickness requirement for the stabilized layer should be determined from Figure 4.2. No reduction in thickness is allowed due to stabilizing.
Note: A minimum six inches of stabilized material should be used.
Stabilization results in improved performance and durability. Materials to be stabilized with cement or lime should attain a minimum unconfined compressive strength of 5,170 kPa (750 psi), using curing periods of 7 days for cement stabilization and 28 days for lime stabilization.

4.8.3. General Construction Guidance. The following guidance applies to stabilizing with cement and/or lime. Construction of stabilized layers should only be performed when temperatures will remain above 40^{o} F throughout construction and curing.

4.8.3.1. Subgrade. The subgrade which will support the stabilized material should be firm and uniform. Wind-rowing the in-place material to be stabilized, thereby exposing the subgrade, allows the subgrade to be worked and any problems corrected before placing the stabilized layer. The subgrade should be rolled with the largest roller available -- either a rubber-tired or steel-wheeled roller. Any weak areas that yield or move excessively under the roller should be replaced with a select fill material.

4.8.3.2. Pulverizing. Material to be stabilized should be pulva-mixed before placing the stabilizing agent. Pulva-mixing should be continued until the material to be stabilized passes 100 percent of the 1 inch U.S. Standard Sieve, and 50 to 60 percent passes the No. 4 U.S. Standard Sieve. Pulverizing ensures proper mixing and reaction with all of the material. If the material is not well-pulverized, clay balls or zones of weak, unstabilized material may result in subsequent poor performance of the airfield.

4.8.3.3. Mixing. The material to be stabilized should be at optimum moisture content when the stabilizing agent is added. The stabilizing agent should be uniformly distributed over the surface of the airfield. Mixing should continue with the pulva-mixer until the material is uniform in color through the depth of the layer being stabilized. Streaks or stripes are indications that mixing has not been thorough and weak areas will result if the mixing is not continued. Add water as needed to maintain optimum moisture content. If the weather is dry and windy, moisture will be lost rapidly during mixing, requiring more frequent additions of water.

4.8.3.4. Grade Control. If the material must be stabilized in-place, it should be brought to the final grade and the final elevation, plus an additional thickness for the expected reduction due to compaction, after pulverizing and before the addition of the stabilizing agent. The addition of the stabilizing agent and subsequent mixing should not significantly affect the grades and elevations. A reduction of 10 to 30 percent in layer thickness can be expected due to compaction. A small trial section should be constructed to determine the loss in thickness that can be expected for the local conditions. It is important that the materials be placed as close as possible to final grades prior to compaction. Minor adjustments in the grades following initial compaction can result in thin layers of material that may delaminate and cause potential FOD and roughness problems. Once compaction is begun, the grades should not be adjusted. If the grades have to be adjusted, a minimum depth of six inches of material should be pulva-mixed, the grade adjusted, and then compaction begun again.

4.8.3.5. Compaction. Compaction should begin as soon as possible after mixing with cement stabilization. In no case should compaction be finished later than four hours after the start of mixing of the cement mixture. Roller patterns may be adjusted until the minimum number of passes results in the density required. The required density should be at least 95 percent of the mix design density. For lime stabilization, compaction may be delayed as long as 24 hours. The materials should be kept near optimum moisture content after mixing and before compaction occurs. The delay in compaction allows the material to react chemically (a process termed "mellowing" for lime stabilized materials).

4.8.3.6. Curing. Curing is required to maintain the moisture content and allow the hydration process to continue uninterrupted, thereby allowing the stabilized material to achieve maximum strength. Normally, spray-on membranes, such as a bitumen or a curing compound, may be used for curing. However, since the stabilized layer will be the airfield surface, membranes are not recommended. Sprinklers, hay, or burlap blankets can be used for moist curing. Plastic sheeting that can be removed after the curing period may also be used. The curing period should last at least seven days, but curing beyond seven days will help the stabilized material develop maximum strength. If sprinklers or other systems are used for wet curing, the surface should be monitored to ensure that surface erosion does not occur.

4.9. Design Parameters. The design of contingency airfields requires a knowledge of the design aircraft, the gross weight of the aircraft, the mission traffic requirements, the type of traffic area, preliminary soil strength data, and frost conditions. Each of these parameters is described below.

4.9.1. Design Aircraft. The criteria presented is for the design of contingency airfields exclusively for the C-17 aircraft. If the C-17 is to be used in conjunction with other aircraft (i.e. C-130), the C-17 will be the critical aircraft for the structural design of contingency airfields.

4.9.2. Aircraft Gross Weight. The gross weight of the aircraft is the combined weight of the empty aircraft, the cargo, and the fuel. The operating weight of the C-17 aircraft is 279,000 lbs or 279 kips. The maximum gross weight of the aircraft is 586 kips. However, the maximum gross weight for operations on contingency airfields for the C-17 aircraft is 447 kips which is also typically the design gross weight for contingency operations.

4.9.3. Mission Traffic Requirements. The mission traffic requirements refer to the number of aircraft passes that an airfield must sustain in order to fulfill mission requirements. Contingency airfields typically have a short design life, and a reasonable estimate of the mission's requirements in terms of aircraft passes is required in order to produce an adequate airfield design with the minimum resource requirements. From the mission statement or an estimate of the situation, determine the minimum number of design aircraft passes that will accomplish the mission. For contingency airfields that have a parallel taxiway, one aircraft pass is defined as one takeoff and one landing. For contingency airfields that do not possess a parallel taxiway, one aircraft landing and one takeoff each count as an aircraft pass. Thus, if an airfield is to be designed for 100 aircraft operations (landings and takeoffs), the design aircraft passes would be 100 if the design includes the construction of a parallel taxiway. If a parallel taxiway is not in the overall design, then the design aircraft passes should be 200. Additional design passes should be incorporated if multiple aircraft movements are expected on the airfield. For each additional movement expected, one design aircraft pass should be added to the design traffic level.

4.9.4. Traffic Area. Military airfields are typically divided into traffic areas based upon the frequency and type of aircraft loading. All pavement facilities of contingency airfields are classified as Type A traffic areas. Type A traffic areas are pavement facilities that receive channelized traffic and the full design weight of the aircraft.

4.9.5. Soil Strength. The strength of the in-place subgrade will determine the type of surfacing required (if any) and the allowable number of passes of the design aircraft. The strength of the subgrade and construction materials can be determined in terms of the California Bearing Ratio (CBR) by using the laboratory CBR test, airfield cone penetrometer, trafficability penetrometer, or the Dynamic Cone Penetrometer (DCP). The soil strengths in terms of CBR can be determined based upon procedures outlined in Chapter 5, FM 5-430-00-1/AFPAM 32-8013, Vol. 1. A preliminary site investigation is essential in order to properly design contingency airfields. The procedure for conducting site evaluations is provided in Appendix C of this document.

4.9.6. Frost Conditions. Frost action can cause subgrade strengths to be reduced significantly during thaw periods. Detrimental frost action will occur if the subgrade contains frost-susceptible materials, the temperature remains below freezing for a considerable amount of time, and an ample supply of ground water exists. If the subgrade is frost-susceptible, determine its frost group from Table 4.5 below (FM 5-430-00-1/AFPAM 32-8013, Vol. 1.

Table 4.5. Frost Group Designations for Frost Design based on Soil Classification

Frost Group	Type of Soil	% by Weight < 0.02 mm	Typical Soil Types under the USCS
NFS	(a.) Gravels (e > 0.25)	0-3	GW, GP
	Crushed Stone	0-3	GW, GP
	Crushed Rock	0-3	GW, GP
	(b.) Sands (e < 0.30)	0-3	SW, SP
	(c.) Sands (e > 0.30)	3-10	SP
S1	(a.) Gravels (e < 0.25)	0-3	GW, GP
	Crushed Stone	0-3	GW, GP
	Crushed Rock	0-3	GW, GP
	(b.) Gravelly soils	3-6	GW, GP, GW-GM, GP-GM, GW-GC, and GP-GC
S2	Sandy soils (e < 0.30)	3-6	SW, SP, SW-SM, SP-SM, SW-SC, and SP-SC
F1	Gravelly soils	6-10	GW-GM, GP-GM, GW-GC, and GP-GC
F2	(a.) Gravelly soils	10-20	GM, GC, GM-GC
	(b.) Sands	6-15	SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, and SM-SC
F3	(a.) Gravelly soils	>20	GM, GC, GM-GC
	(b.) Sands (not very fine silty sands)	>15	SM, SC, SM-SC
	(c.) Clays (PI > 12)	-	CL, CH, ML-CL
F4	(a.) Silts	-	ML, MH, ML-CL
	(b.) Very fine sands	>15	SM, SC, SM-SC
	(c.) Clays (PI < 12)	-	CL, ML-CL
	(d.) Varved clays or fine-grained banded sediments	-	CL or CH layered with ML, MH, SM, SC, SM-SC, or ML-CL
NOTE: e = void ratio. NFS indicates non-frost susceptible material			

To design for the effects of frost, Frost Area Soil Support Indexes (FASSIs) are used in lieu of CBRs. Table 4.6 below lists these indexes for the different frost groups in Table 4.5. The design of contingency airfields for frost conditions is addressed later.

Table 4.6. Frost Area Soil Support Indexes (FASSIs)

Frost Group of Soils	Frost Area Soil Support Index
NFS	In-place CBR
F1 and S1	9
F2 and S2	6.5
F3 and F4	3.5

4.10. Surface CBR and Thickness Design. The criteria presented herein describes the design of unsurfaced, aggregate-surfaced, and AM-2 mat-surfaced contingency airfields. The first step in all designs is to obtain the site reconnaissance or investigation data to determine existing site conditions. Divide the subsurface soil strength data into layers of varying thickness by grouping materials possessing similar CBR values. The procedure for determining the soil strength for the various layers is outlined in AFJPAM 32-8013 and Appendix C of this document. The second step in the design of contingency airfields for the C-17 aircraft is to determine the design aircraft loading and the number of aircraft passes required to support mission requirements.

4.10.1. Unsurfaced Design. This design criteria consists of the determination of a minimum surface CBR value and a minimum thickness of material equal to or greater than the minimum surface CBR over a lower strength material. The existing soil conditions must meet both the surface CBR requirement and the thickness requirements. To determine if the surface CBR is sufficient to sustain the design traffic, enter Figure 4.1 with the required number of aircraft passes. Proceed vertically until the pass level intersects the appropriate design gross weight of the aircraft. Finally, trace a horizontal line from this intersection to the required subgrade CBR value. The CBR obtained is the surface soil strength required to support the design aircraft load at the required pass level. If the CBR obtained from Figure 4.1 is greater than the in-place subgrade CBR determined from the preliminary site investigation, the airfield will require structural improvement to support mission requirements. If the CBR obtained from Figure 4.1 is equal to or less than the in-place subgrade CBR, the surface CBR requirement is met. If the in-place surface CBR is only slightly less than the minimum CBR, scarify and compact the in-place material. Then, reevaluate the subgrade soil strength by one of the methods described above and compare the compacted in-place CBR to the required CBR from Figure 4.1. Next, determine the minimum thickness of the required CBR from Figure 4.2. Enter Figure 4.2 at the top with the in-place subgrade CBR and draw a vertical line down until it intersects the design gross weight of the aircraft. Then, draw a horizontal line from this point until it intersects the required design passes. Finally, draw a vertical line down from the required pass level until it intersects the required thickness. This thickness is the required thickness in inches of a material of the minimum surface CBR determined from Figure 4.1 necessary to support mission requirements. If the in-place subgrade CBR is equal to or greater than the minimum subgrade CBR determined from Figure 4.1 and the preliminary site investigation revealed that the depth of the in-place subgrade CBR is equal to or greater than the thickness determined from Figure 4.2, then the airfield is structurally adequate to support the design traffic. If a weaker soil layer is encountered at some depth below the surface soil layer, the thickness of material required to protect the weaker soil layer should be checked using Figure 4.2. Enter Figure 4.2 with the weak layer's CBR rather than the surface layer's CBR. If the thickness of the surface layer is not sufficient to protect the underlying weak layer, the airfield requires structural improvement to withstand the design traffic. Structural improvements for contingency airfields include the addition of an aggregate or select fill layer(s), stabilization of the natural subgrade (as discussed previously), or the use of AM-2 matting. The design criteria for aggregate-surfaced and AM-2 mat-surfaced airfields is presented below.

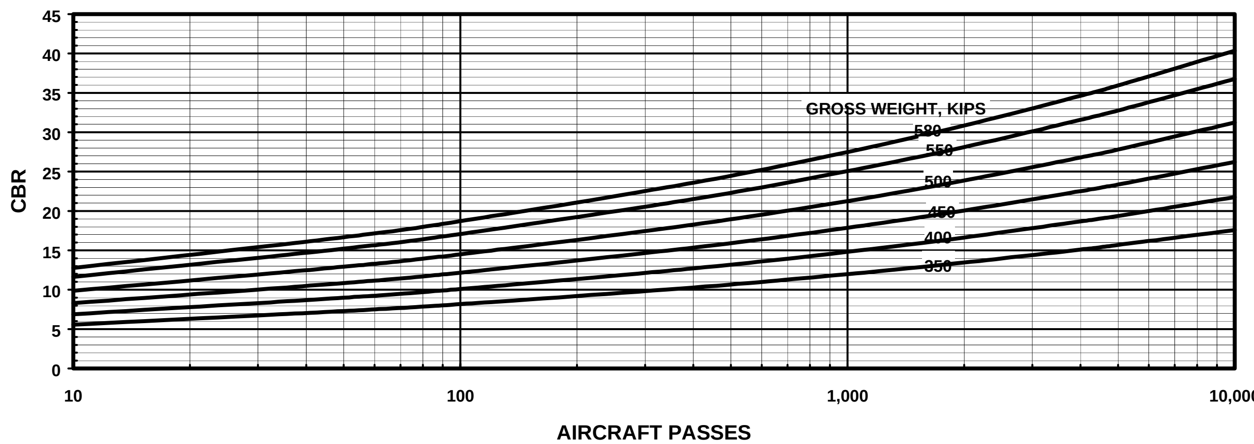


Figure 4.1. Unsurfaced Strength Requirements for the C-17 Aircraft

4.10.2. Aggregate-Surfaced Design. The design of an aggregate-surfaced contingency airfield for the C-17 aircraft is necessary if the in-place subgrade CBR cannot support the design mission requirements. The first step was accomplished by evaluating the proposed site for the unsurfaced criteria. Doing so provides the designer with the minimum required surface CBR to support C-17 aircraft operations at the design pass level. The next step is to use Figure 4.2 to determine the minimum required thickness of the minimum CBR determined from Figure 4.1.

4.10.3. AM-2 Mat-Surfaced Design. Heavy cargo aircraft may not be able to operate on unsurfaced airfields due to the soil strength requirements. The use of an AM-2 mat surfacing may be a plausible solution. For satisfactory performance, the landing mat must be supported by the subgrade and must not be required to bridge over depressions. To determine if the subgrade is capable of supporting an AM-2 surfaced airfield, the minimum required subgrade CBR must be determined from Figure 4.3 and compared to the in-place subgrade CBR. Enter Figure 4.3 at the bottom with the

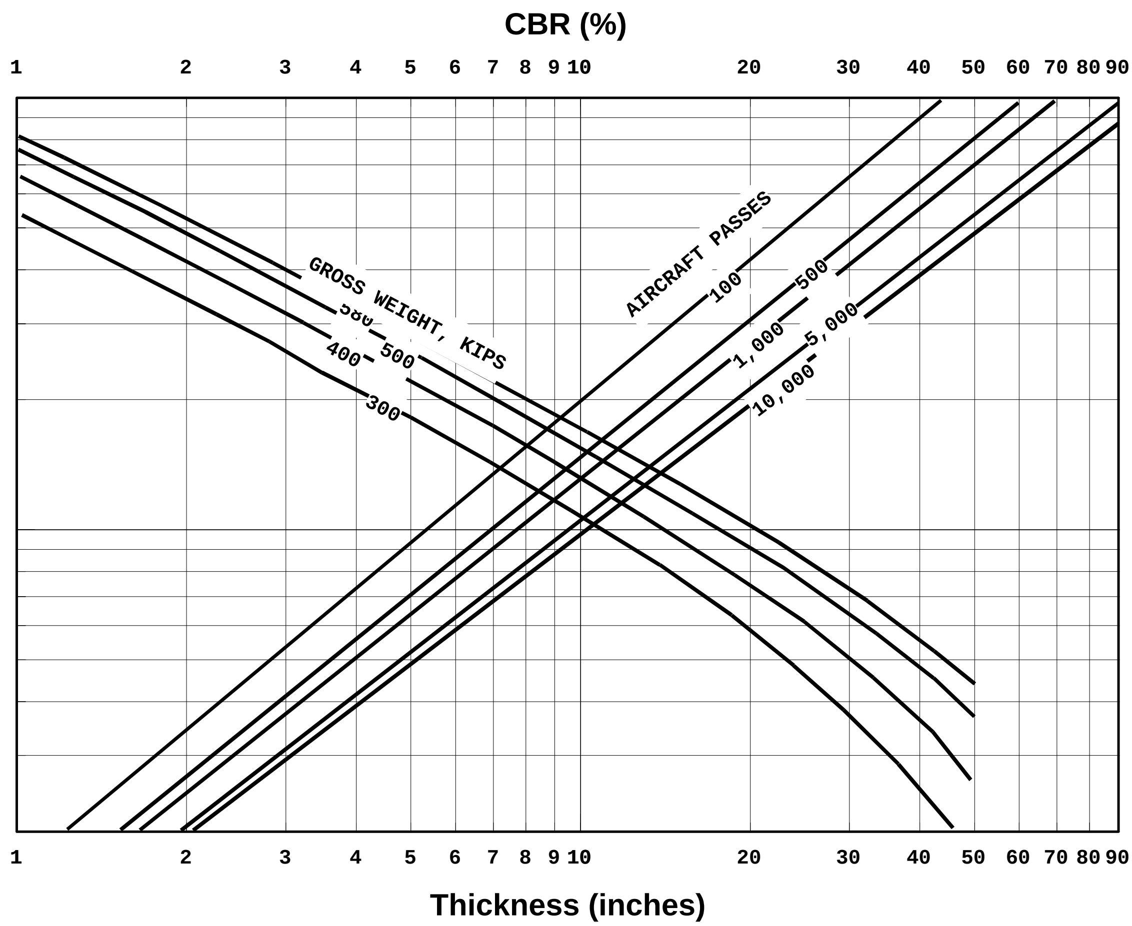


Figure 4.2. Aggregate or Select Fill Surface Thickness Requirements for the C-17 Aircraft.

required number of aircraft passes and draw a vertical line to the intersection of the appropriate design gross weight curve. Then, draw a horizontal line to the vertical axis to determine the minimum required subgrade CBR. Now that the required subgrade CBR has been determined, it is necessary to check the subgrade thickness requirements. Use Figures 4.4 through 4.8 to find the thickness of the subgrade that is required at the predetermined soil strength (from Figure 4.3) for different design gross weights of the aircraft. Use the in-place subgrade CBR when using Figures 4.4 through 4.8 to determine the minimum thickness requirements. For example, enter Figure 4.6 for a C-17 aircraft with a design gross weight of 450,000 lbs. at the bottom with the in-place subgrade CBR. Draw a vertical line from the in-place subgrade CBR to the intersection of the appropriate design pass level. Then, draw a horizontal line from this intersection to the vertical axis to determine the thickness of subgrade (at the required strength) that must exist beneath the AM-2 matting. If the preliminary site investigation indicates that the in-place subgrade CBR is greater than or equal to the minimum required CBR obtained from Figure 4.3 and that the in-place soil strength is consistent for a depth equal to or greater than the thickness required in Figures 4.4 through 4.8, then AM-2 mat surfacing will be adequate to sustain the mission's design traffic. Otherwise, AM-2 matting will not provide sufficient structural improvement to the natural subgrade to support the design C-17 operations. **Figures 4.3**

through 4.8 should not be used for Navy and Marine airfields since their criteria require a minimum CBR of 25 under AM-2 surfaced airfields.

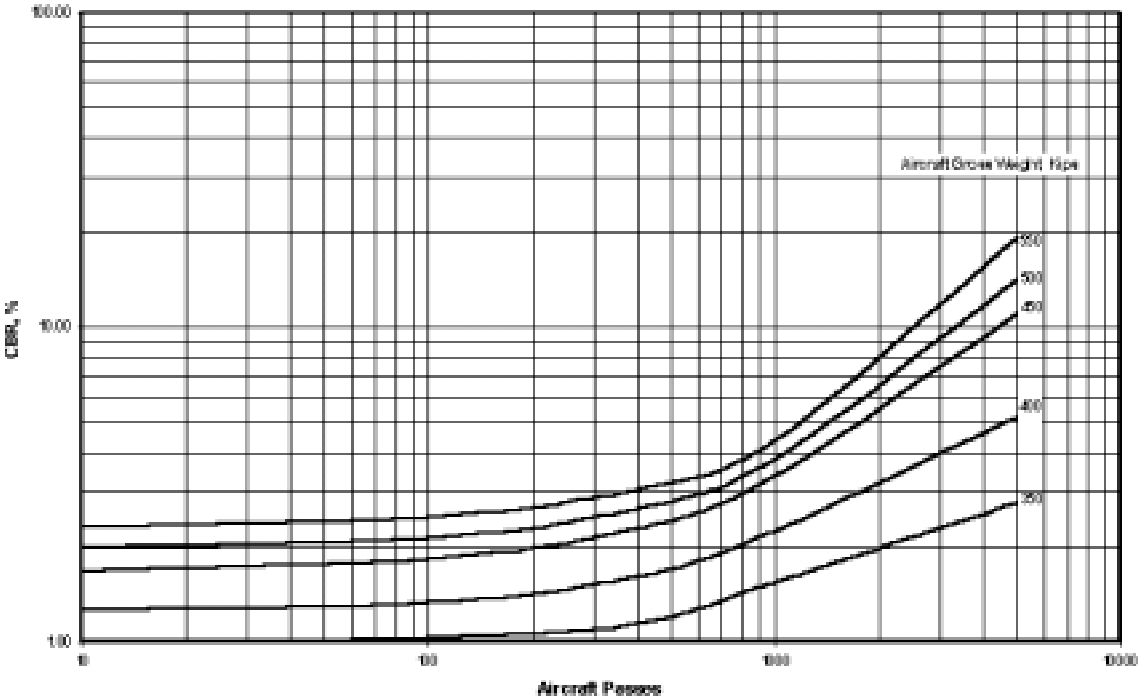


Figure 4.3. Soil Strength Requirements for the C-17 on AM-2 Mat

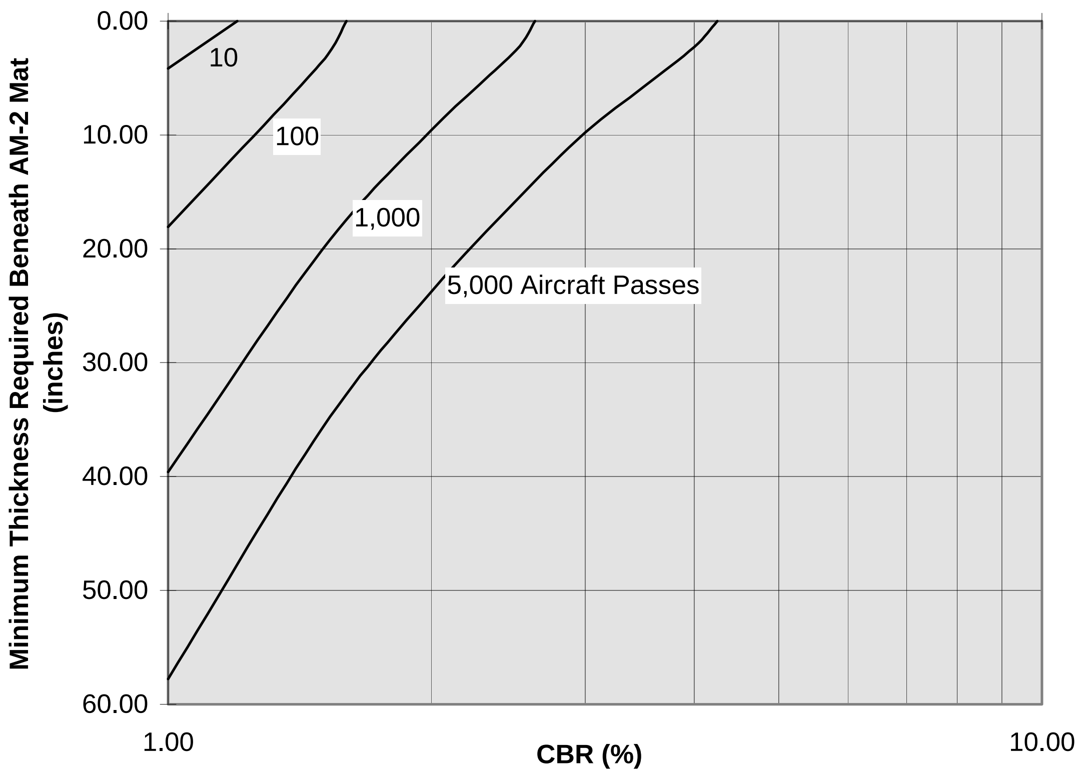


Figure 4.4. Design Curve for C-17 Operations on AM-2 Mat at 350,000 Pounds

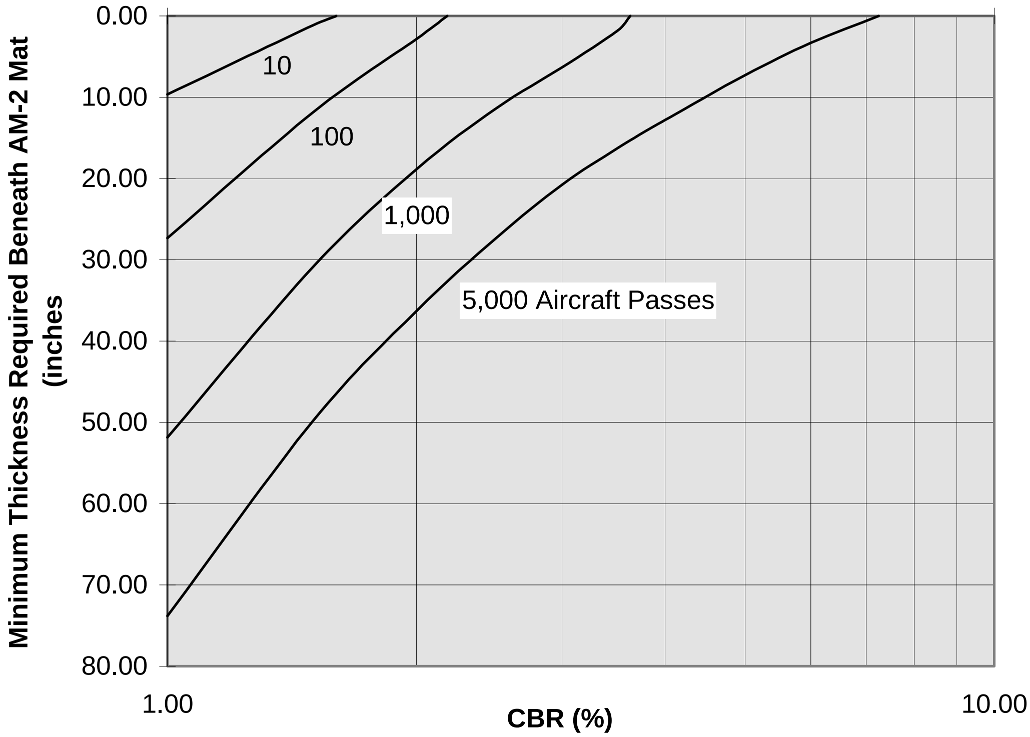


Figure 4.5. Design Curve for C-17 Operations on AM-2 Mat at 400,000 Pounds

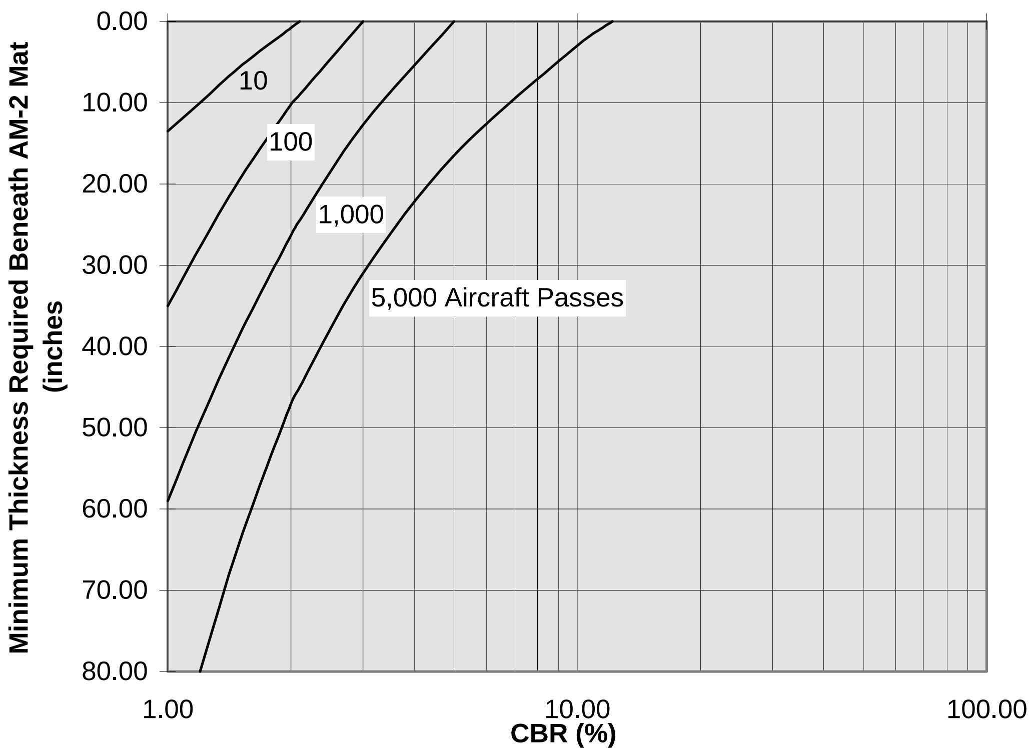


Figure 4.6. Design Curve for C-17 Operations on AM-2 Mat at 450,000 Pounds

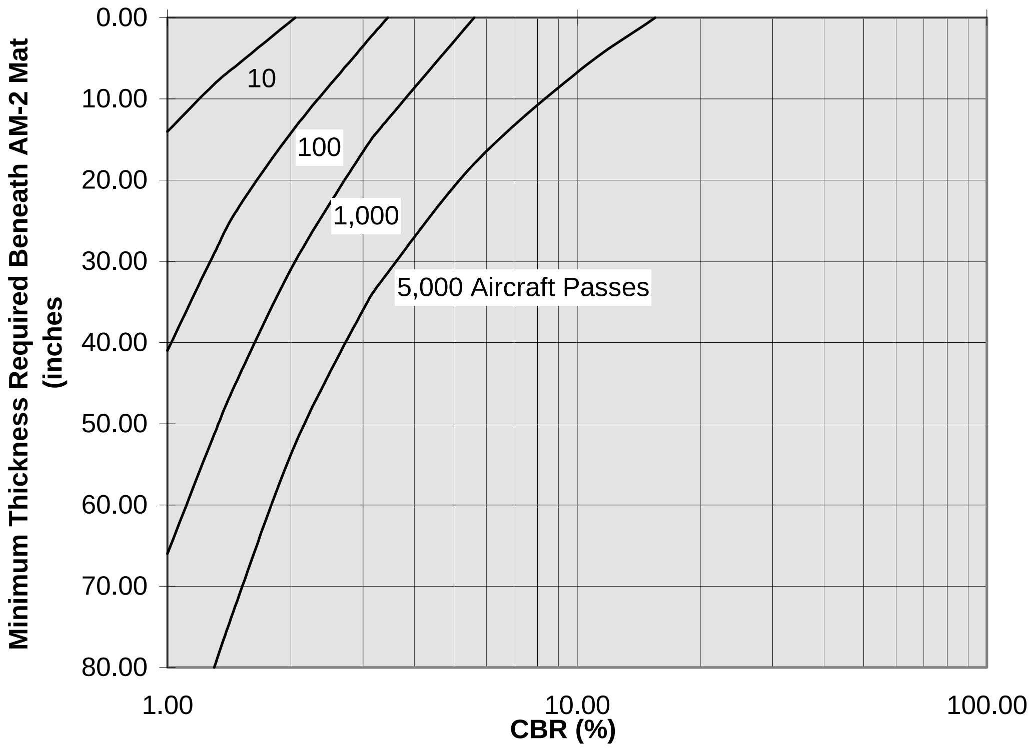


Figure 4.7. Design Curve for C-17 Operations on AM-2 Mat at 500,000 Pounds

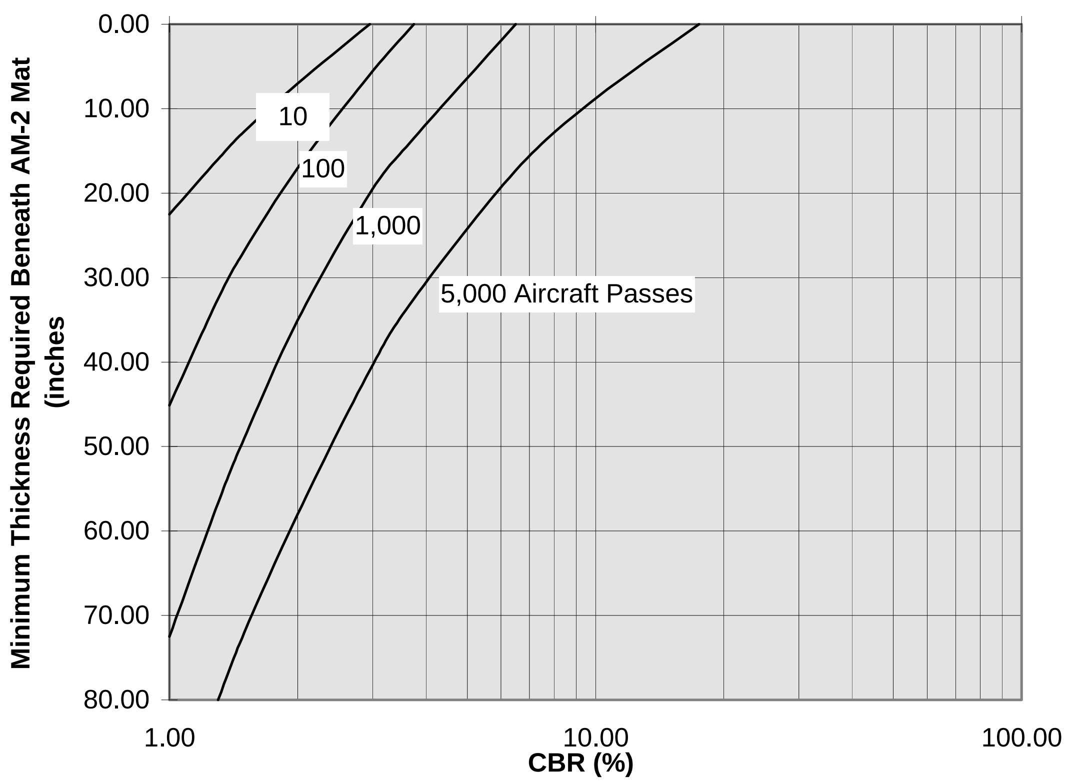


Figure 4.8. Design Curve for C-17 Operations on AM-2 Mat at 550,000 Pounds

4.10.4. Design for Frost Conditions. Typically, contingency airfields are not designed for protection against frost action due to their short design life. However, in some contingency situations, designing for frost conditions may be warranted. The design for frost conditions utilizes the reduced subgrade strength criteria which assigns a material to a frost group based upon the material's properties. Table 4.5 shows the frost group designations for various material types. Each material is then assigned a Frost Area Soil Support Index (FASSI) number based upon its frost group designation. The FASSI numbers for each frost group are illustrated in Table 4.6. The material's FASSI number is then used in lieu of the in-place subgrade CBR to enter the design curves. Therefore, to design for frost conditions determine the material's FASSI number, then perform a typical contingency design utilizing the FASSI number instead of the in-place subgrade CBR. However, if the FASSI designation is greater than the in-place soil's CBR, the in-place soil's CBR should be used for the final design. For a more detailed frost design refer to AFM 88-6, Chapter 4.

4.11. Design Examples. To illustrate usage of the design criteria outlined above, several examples are provided below for designing contingency airfields for various C-17 aircraft missions.

4.11.1. Example 1. Design an airfield in the theater of operations for 200 operations of a C-17. A special tactics team determined that the soil's in-place CBR was 16 for a depth of approximately 24 inches beyond which there is a 12-inch layer of 10 CBR material. The airfield's geometric design does not include a parallel taxiway.

> Note: The number of required passes should be multiplied by two to account for the aircraft taxiing down the runway to takeoff or unload cargo.

> Step 1. The design aircraft has been designated as the C-17. The design gross weight of the C-17 is 447 kips which seems reasonable in regard to mission requirements.

> Step 2. The design aircraft passes stated were 200, however, for design purposes (as noted above) 400 passes will be used to account for taxi movements.

> Step 3. Using Figure 4.1, determine the minimum required subgrade strength to support 400 passes of a 447 kip C-17 aircraft. Enter Figure 4.1 with 400 passes and draw a vertical line to just below the 450 kip gross weight curve. From this point, draw a horizontal line to the vertical axis to determine the required CBR. The required subgrade CBR for 400 passes of a 447 kip C-17 is approximately 15 CBR.

> Step 4. Since the minimum required CBR is less than the in-place CBR (15 < 16), then the in-place subgrade surface strength is sufficient to support mission

requirements. It must also be determined if adequate thickness of the 16 CBR material is available. Enter Figure 4.2 at the top with the in-place subgrade CBR (16) and draw a vertical line down until it intersects the design gross weight of the C-17 or 447 kips. Next, draw a horizontal line from this intersection until it intersects the design pass level of 400 passes. Finally, draw a vertical line from this intersection downward until you intercept the required thickness. Seven inches of 16 CBR material is required to support 400 passes of a 447 kip C-17 aircraft. Since the in-place soil has 24 inches of 16 CBR material, the unsurfaced airfield can support the design aircraft for the design passes without structural improvement.

Step 5. Since there is a 12-inch layer of weaker material underlying the surface layer, it must be determined if the surface soil layer has adequate thickness to protect the underlying weaker layer. Enter Figure 4.2 with the weak layer's CBR (10) and draw a vertical line down until it intersects the design gross weight of the aircraft or 447 kips. Next, draw a horizontal line from this intersection until it intersects the design pass level of 400 passes. Finally, draw a vertical line from this intersection downward until you intercept the required material thickness. Nine inches of a 15 CBR material is required to protect the weak subsurface soil layer. Since the in-place soil has 24 inches of a 16 CBR material, the weak layer is adequately protected and the design is valid.

4.11.2. Example 2. Developments in the theater of operations require the design of a second contingency airfield to support 200 passes of a C-17. The special tactics team determined that the soil's in-place CBR at the second site is 12 for a depth of approximately 20 inches beyond which the CBR of the material increased. This airfield will not possess a parallel taxiway.

Step 1. The design aircraft has been designated as the C-17. The design gross weight of the C-17 is 447 kips which seems reasonable in regard to mission requirements.

Step 2. The design aircraft passes stated were 200, however, for design purposes (as noted in Example 1) 400 passes will be used to account for taxi movements.

Step 3. Using Figure 4.1, determine the minimum required subgrade strength to support 400 passes of a 447 kip C-17 aircraft. Enter Figure 4.1 with 400 passes and draw a vertical line to just below the 450 kip gross weight curve. From this point, draw a horizontal line to the vertical axis to determine the required CBR. The required subgrade CBR for 400 passes of a 447 kip C-17 is approximately 15 CBR.

Step 4. Since the required CBR is greater than the in-place CBR (15 > 12), then the subgrade must be improved structurally to support mission requirements. First, determine the thickness of 15 CBR material required above the subgrade to support mission requirements. Enter Figure 4.2 at the top with the in-place subgrade CBR (12) and draw a vertical line down until it intersects the design gross weight of the C-17 or 447 kips. Next, draw a horizontal line from this intersection until it intersects the design pass level of 400 passes. Finally, draw a vertical line from this intersection downward until you intercept the required thickness. The design requires 8 inches of 15 CBR material be placed over the in-place subgrade in order to support 400 passes of a 447 kip C-17 aircraft.

4.11.3. Example 3. Developments have led to the need for a contingency airfield. Estimation of the mission suggests that the design pass level should be 1,000 passes of a 447 kip C-17. The only available site has a CBR of 4 for a depth of 12 inches where it increases to an 8 CBR for an additional 24 inches.

Note: The mission requirements include plans for a parallel taxiway and a small apron. Thus, the number of required passes should remain at 1,000 due to the probability that the aircraft will use the taxiway and apron for all movements other than takeoffs or landings.

Step 1. The design aircraft has been designated as the C-17. The design gross weight of the C-17 is 447 kips which seems reasonable in regard to mission requirements.

Step 2. The design aircraft passes stated were 1,000. All pavements are A type traffic areas and will use the same design.

Step 3. Using Figure 4.1, determine the minimum required subgrade strength to support 1,000 passes of a 447 kip C-17 aircraft. Enter Figure 4.1 with 1,000 passes and draw a vertical line to just below the 450 kip gross weight curve. From this point, draw a horizontal line to the vertical axis to determine the minimum required CBR. The required subgrade CBR for 1,000 passes of a 447 kip C-17 is approximately 18 CBR.

Step 4. Since the required CBR is greater than the in-place CBR (18 > 4), then the subgrade must be improved structurally to support mission requirements. First, determine the thickness of 18 CBR material required above the in-place subgrade to support mission requirements. Enter Figure 4.2 at the top with the in-place subgrade CBR (4) and draw a vertical line down until it intersects the design gross weight of the C-17 or 447 kips. Next, draw a horizontal line from this intersection until it intersects the design pass level of 1,000 passes. Finally, draw a vertical line from this intersection downward until you intercept the required thickness. The design requires 21 inches of 18 CBR material be placed over the in-place subgrade in order to support 1,000 passes of a 447 kip C-17 aircraft.

Step 5. Available aggregate and construction resources are limited, and the construction of a 21-inch structural layer would be prohibitive. A stockpile of AM-2 landing mat is available, and a decision is made to determine the plausibility of an AM-2 mat-surfaced airfield. First, determine the minimum subgrade surface

CBR requirements beneath the landing mat from Figure 4.3. Enter the chart at the bottom with the design aircraft passes (1,000) and draw a vertical line until it intersects the design gross weight of the aircraft. From this intersection, draw a horizontal line across to the vertical axis to determine the minimum subgrade CBR that is required beneath the AM-2 mat. The required subgrade CBR for 1,000 passes of a 447 kip C-17 on AM-2 landing mat is 3.2 CBR or ~ 3.5 CBR.

Step 6. Since the required subgrade CBR beneath the AM-2 matting is less than the existing in-place subgrade CBR (3.5 < 4), the surface CBR requirements are met. Next, determine the minimum thickness of the subgrade required to support the mission's design traffic. Enter Figure 4.6 for a 450 kip C-17 with the in-place CBR of 4 and draw a vertical line until it intersects the design pass level of 1,000. Then, draw a horizontal line until it intersects the vertical axis to determine the minimum thickness of 4 CBR material required beneath the AM-2 matting. A thickness of 5 inches of 4 CBR material is required beneath the AM-2 mat to support 1,000 passes of a 447 kip C-17. Since the in-place CBR of 4 exists for a depth of 12 inches, the thickness requirements beneath AM-2 mat are met and AM-2 mat-surfacing is sufficient to support the design mission traffic.

4.11.4. Example 4. Information provided by headquarters indicates that the airfield in Example 3 will be required to support 5,000 passes of a C-17 rather than the original 1,000 passes. Redesign the airfield accordingly.

Step 1. The design aircraft and its design gross weight are denoted above as a 447 kip C-17.

Step 2. Due to changes in mission requirements, the design pass level was increased from 1,000 passes to 5,000 passes.

Step 3. Following the guidance in Step 3 of the example above, the unsurfaced criteria minimum surface CBR requirement is determined to be a 23 CBR. Since the in-place subgrade CBR is much less than the required subgrade CBR (4 < 23), the in-place subgrade must be improved structurally to support the mission's design traffic.

Step 4. Use the guidance in step 4 of the above example to determine the minimum required thickness of an aggregate or select fill layer of at least a 23 CBR to be placed above the in-place subgrade material. The criteria in Figure 4.2 indicate that approximately 25 inches of a 23 CBR material is required to support 5,000 passes of a 447 kip C-17.

Step 5. Since logistics prohibits the use of a large amount of fill, AM-2 mat-surfacing should be considered. As shown in step 5 above, determine the minimum surface subgrade CBR required to support AM-2 matting for the design mission traffic. From Figure 4.3, it is determined that a 10 CBR material is required to support mission requirements. Since the in-place subgrade CBR is less than the required CBR (4 < 10), the in-place subgrade must be structurally improved.

Step 6. To determine the thickness required of the 10 CBR material, use the guidance in step 6 above and Figure 4.6. Entering the figure with the in-place subgrade CBR (4) indicates that 22 inches of a 10 CBR is required beneath the AM-2 mat to support design traffic requirements.

Thus, the design of the airfield includes the construction of a 22-inch select fill or aggregate layer of at least a 10 CBR to be placed on top of the 4 CBR in-place subgrade. The surfacing will consist of the use of AM-2 matting for all traffic areas. Alternate designs incorporating various layers of differing soil strengths may be considered provided that they meet the criteria presented herein.

4.11.5. Example 5. Design an airfield for contingency operations of a C-17 in an area susceptible to frost action. 50 passes are expected during the spring thaw period. Preliminary site investigations identified that the subgrade was classified as a low-plasticity clay (CL) with a Plasticity Index (PI) of 15 and an in-place subgrade CBR of 10 for 36 inches. No taxiways will be constructed.

Step 1. The design aircraft is a 447 kip C-17.

Step 2. The expected number of aircraft passes is 50, but the airfield will not have any taxiways so the design pass level is adjusted to 100 (see Note in Example 1).

Step 3. The first step in designing for frost is to determine the Frost Group to which the subgrade belongs. Using the site investigation data and Table 4.1, it is determined that the subgrade is in the F3 Frost Group. The next step is to determine the Frost Area Soil Support Index (FASSI) for the subgrade. Using Table 4.2, the FASSI for an F3 material is 3.5.

Step 4. Since the FASSI is less than the in-place subgrade CBR (3.5 < 10), then the FASSI must be used in lieu of the in-place CBR for determining soil strength and thickness requirements. Enter Figure 4.1 with the design passes (100) and the gross aircraft weight (447 kips) to determine the subgrade surface CBR required to support the design mission traffic. Following the steps in Example 1, Step 3, it is determined that a minimum surface CBR of 12 is required to support 100 passes of a 447 kip C-17.

Step 5. Since the minimum required surface CBR is greater than the in-place subgrade CBR for frost design (12 > 3.5), the subgrade requires structural improvement to withstand the design traffic. Using Figure 4.2, enter the chart with an in-place subgrade CBR of 3.5 to determine the thickness of 12 CBR material required above the subgrade to support the design traffic. Following the guidance in Example 1, Step 4, it is determined that 15 inches of 12 CBR material is required above the 3.5 CBR (frost) subgrade.

At this point, an analysis of available construction materials would determine whether 15 inches of an 12 CBR non frost-susceptible material would be plausible. If not, the design procedure for the use of AM-2 matting should proceed if sufficient mat is available. Otherwise, alternate means of strengthening the in-place subgrade should be explored as discussed earlier.

4.12. Drainage Design. Adequate surface drainage should be provided in order to minimize moisture damage to the airfield. The rapid removal of surface water reduces the potential for absorption and helps to ensure more consistent soil strength. The surface geometry of the airfield should be designed so that drainage is provided at all points. Depending upon the surrounding terrain, surface drainage may be achieved by a continual cross slope or by an interconnected series of cross slopes. Except in special circumstances the two year storm frequency is considered a satisfactory design frequency for contingency airfields. Design of surface drainage should be in accordance with TM 5-820-3/AFM 88-5, Chapter 3. Requirements for subsurface drainage are outlined in TM 5-820-2/AFM 88-5, Chapter 2.

4.13. Dust Control. The primary objective of a dust palliative is to prevent soil particles from becoming airborne as a result of wind or traffic. Dust palliatives must be able to withstand the abrasion of wheels and tracks. The abrasive action of aircraft landing gear may be too serious for the use of some dust palliatives. However, the use of dust palliatives in non-braking areas should be considered especially in arid and semi-arid climates. No one product has been identified as universally acceptable for all problem situations that may be encountered. Several materials have been recommended for use and are discussed in TM 5-830-3/AFM 88-17, Chapter 3.

APPENDIX A

Classification and Field Identification of Soils

A.1. Soil Classification. Soils seldom exist separately as sand, gravel, or any other single component in nature. They are usually mixtures with varying proportions of different sized particles. Each component contributes to the characteristics of the mixture. The Unified Soil Classification System (USCS) is based on the characteristics which indicate how a soil will behave as a construction material. The physical properties determined by appropriate tests and calculations are used to classify the soil. The criteria for identifying the different soil types is described in Table A.1 and the following paragraphs. Table A.2 depicts engineering characteristics of the different soil types pertinent to roads and airfields.

Major Divisions			Symbol	Field Identification Procedures (Base fractions on estimated weights)
Coarse-grained Soils More than half of material is larger than No. 200 sieve	**Gravels** More than half of coarse fraction is larger than No. 4 sieve	Gravels <5% Fines	**GW**	Wide range in grain sizes, all intermediate sizes substantially represented
			GP	Predominantly one size or some intermediate sizes missing
		Gravels >12% Fines	**GM**	Nonplastic fines or fines with little plasticity (see ML below)
			GC	Plastic fines (see CL below)
	Sands More than half of coarse fraction is smaller than No. 4 sieve	Sands <5% Fines	**SW**	Wide range in grain sizes, all intermediate sizes substantially represented
			SP	Predominantly one size or some intermediate sizes missing
		Sands >12% Fines	**SM**	Nonplastic fines or fines with little plasticity (see ML below)
			SC	Plastic fines (see CL below)

Major Divisions		Symbol	Identification Procedures on Fractions smaller than No. 40 sieve		
			Dry Strength	Wet Shake	Thread or Ribbon
Fine-grained Soils More than half of material is smaller than No. 200 sieve	**Silts & Clays** LL <50	**ML**	None to slight	Quick to slow	None
		CL	Medium to high	None to very slow	Medium
		OL	Slight to medium	Slow	Slight
	Silts & Clays LL >50	**MH**	Slight to medium	Slow to none	Slight to medium
		CH	High to very high	None	High
		OH	Medium to high	None to very slow	Slight to medium
Highly Organic Soils		**Pt**	Readily identified by color, odor, spongy feel, and frequently by fibrous texture		

Table A.1. Unified Soil Classification System

Soil Types		Symbol		Value as Subbase or Subgrade	Value as Base Course	Potential Frost Action	Compressibility & Expansion
Coarse-grained Soils	Gravels and Gravelly Sands	GW		Excellent	Good	None to very slight	Almost none
		GP		Good to excellent	Poor to fair	None to very slight	Almost none
		GM	d	Good to excellent	Fair to good	Slight to medium	Very slight
			u	Good	Poor	Slight to medium	Slight
		GC		Fair to good	Poor	Slight to medium	Slight
	Sands and Sandy Gravels	SW		Good	Poor	None to very slight	Almost none
		SP		Fair to good	Poor to Not suitable	None to very slight	Almost none
		SM	d	Good	Poor	Slight to high	Very slight
			u	Fair to good	Not suitable	Slight to high	Slight to medium
		SC		Fair to good	Not suitable	Slight to high	Slight to medium
Fine-grained Soils	Silts and Clays LL <50	ML		Fair to poor	Not suitable	Medium to very high	Slight to medium
		CL		Fair to poor	Not suitable	Medium to high	Medium
		OL		Poor	Not suitable	Medium to high	Medium to high
	Silts and Clays LL >50	MH		Poor	Not suitable	Medium to very high	High
		CH		Poor to very poor	Not suitable	Medium	High
		OH		Poor to very poor	Not suitable	Medium	High
Highly Organic Soils		Pt		Not suitable	Not suitable	Slight	Very high

GM and SM groups are divided into subdivisions d and u for roads and airfields
Suffix d is used when LL $\leq$ 28 and PI $\leq$ 6   Suffix u is used when LL > 28

Soil Types		Symbol		Drainage Characteristics	Unit Dry Weight Lb per Cu Ft	Field CBR	Subgrade Modulus K Lb per Cu In
Coarse-grained Soils	Gravels and Gravelly Sands	GW		Excellent	125 - 140	60 - 80	300 or more
		GP		Excellent	110 - 130	25 - 60	300 or more
		GM	d	Fair to poor	130 - 145	40 - 80	300 or more
			u	Poor to impervious	120 - 140	20 - 40	200 to 300
		GC		Poor to impervious	120 - 140	20 - 40	200 to 300
	Sands and Sandy Gravels	SW		Excellent	110 - 130	20 - 40	200 to 300
		SP		Excellent	100 - 120	10 - 25	200 to 300
		SM	d	Fair to poor	120 - 135	20 - 40	200 to 300
			u	Poor to impervious	105 - 130	10 - 20	200 to 300
		SC		Poor to impervious	105 - 130	10 - 20	200 to 300
Fine-grained Soils	Silts and Clays LL <50	ML		Fair to poor	100 - 125	5 - 15	100 to 200
		CL		Impervious	100 - 125	5 - 15	100 to 200
		OL		Poor	90 - 105	4 - 8	100 to 200
	Silts and Clays LL >50	MH		Fair to poor	80 - 100	4 - 8	100 to 200
		CH		Impervious	90 - 110	3 - 5	50 to 100
		OH		Impervious	80 - 105	3 - 5	50 to 100
Highly Organic Soils		Pt		Fair to poor	-----	-----	-----

GM and SM groups are divided into subdivisions d and u for roads and airfields
Suffix d is used when LL $\leq$ 28 and PI $\leq$ 6   Suffix u is used when LL > 28

Table A.2. Characteristics Pertinent to Airfields

A.1.1. Categories**.** In the USCS, all soils are divided into three major categories: coarse grained, fine grained, and peat. The first two are differentiated by grain size, whereas the third is identified by the presence of large amounts of organic material.

A.1.2. Groups**.** Each of the major categories is further subdivided into groups and a letter symbol is assigned to each group.

Soil Groups	Symbol
Gravel	G
Sand	S
Silt	M
Clay	C

Soil Characteristics	Symbol
Well graded	W
Poorly graded	P
High compressibility	H
Low compressibility	L
Organic (peat)	Pt
Organic (silts and clays)	O
Liquid limits under 50	L
Liquid limits over 50	H

A.1.3. Coarse-Grained Soils. Coarse-grained soils are defined as those in which at least half the material by weight is larger than a No. 200 sieve. They are divided into two major divisions: gravels and sands. A coarse-grained soil is classified as a gravel if more than half the coarse fraction by weight is larger than a No. 4 sieve. It is a sand if more than half the coarse fraction by weight is smaller than a No. 4 sieve.

A.1.3.1. Coarse-Grained Soils with Less Than Five Percent Nonplastic Fines. The first letter of the symbol indicates a gravel or sand. The second letter is determined by the grain size distribution curve.

- GW Well-graded gravels or gravel-sand mixtures.
- GP Poorly-graded gravels or gravel-sand mixtures.
- SW Well-graded sands or gravelly-sands.
- SP Poorly-graded sands or gravelly-sands.

A.1.3.2. Coarse-Grained Soils Containing More Than 12 Percent Fines. The first letter of the symbol indicates a gravel or sand. The second letter is based upon the plasticity characteristics of the portion of the material passing the No. 40 sieve. The symbol M usually designates a fine-grained soil of little or no plasticity. The symbol C is used to indicate that the binder soil is predominantly clayey in nature.

- GM Silty gravels or gravel-sand-silt mixtures. The Atterberg limits plot below the A-line on the plasticity chart in Table A.1, or the plastic index is less than 4.
- GC Clayey gravels or gravel-sand-clay mixtures. The Atterberg limits plot above the A-line with a plastic index of more than 7.

- SM Silty sands or sand-silt mixtures. The Atterberg limits plot below the A-line, or the plastic index is less than 4.
- SC Clayey sands or sand-clay mixtures. The Atterberg limits plot above the A-line with a plastic index of more than 7.

A.1.3.3. Borderline Coarse-Grained Soils. Coarse-grained soils which contain between 5 and 12 percent of material passing the No. 200 sieve are classified as borderline and are given a dual symbol (for example, GW-GM). Select the two that are believed to be the most representative of the probable behavior of the soil. In cases of doubt, the symbol representing the poorer of the possible groupings should be used, depending upon the judgment of the engineer, from the standpoint of the climatic region.

A.1.4. Fine-Grained Soils. Fine-grained soils are those in which more than half the material by weight passes a No. 200 sieve. Fine-grained soils are not classified on the basis of grain-size distribution, but according to plasticity and compressibility.

A.1.4.1. Silts.

- ML Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity. The plastic index plots below the A-line and the liquid limit is less than 50.
- MH Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, plastic silts. The plastic index plots below the A-line and the liquid limit is more than 50.
- OL Organic silts and organic silt-clays of low plasticity. The plastic index plots below the A-line and the liquid limit is less than 50.

A.1.4.2. Clays.

- CL Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, and silty clays, lean clays. The plastic index plots above the A-line and the liquid limit is less than 50.
- CH Inorganic clays of high plasticity, fat clays. The plastic index plots above the A-line and the liquid limit is more than 50.
- OH Organic clays of medium to high plasticity. The plastic index plots below the A-line and the liquid limit is more than 50.

A.1.4.3. Borderline Fine-Grained Soils. Fine-grained soils which plot in the shaded portion of the plasticity chart are borderline cases and should be given dual symbols (for example, CL-ML).

A.1.5. Highly Organic Soils. A special classification (Pt) is reserved for the highly organic soils, such as peat, which have many characteristics undesirable for use as foundations and construction materials. No laboratory criteria are established for these soils, as they can be identified in the field by their distinctive color, odor, spongy feel, and fibrous textures. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

A.2. Field Identification of Soil. Lack of time and facilities often make laboratory testing impossible in contingency evaluations. Even where laboratory tests are to follow, field identification tests can reduce the number of laboratory test samples required. In expedient evaluations where the DCP is the primary instrument used to determine soil strength, proper identification of soil type is required to determine the correct correlation factor to be used in computing CBRs. The correlations for CL and CH soils vary significantly from other materials (see Tables C.2 and C.3 and Figure C.6 in Appendix C). Experience is the greatest asset in field identification and this is gained by getting the feel of soils during laboratory testing. If expedient field tests to identify clay soils are inconclusive, testing should be conducted using laboratory Atterberg limits equipment and procedures. Figure A.1 outlines a step-by-step procedure to field classify soil.

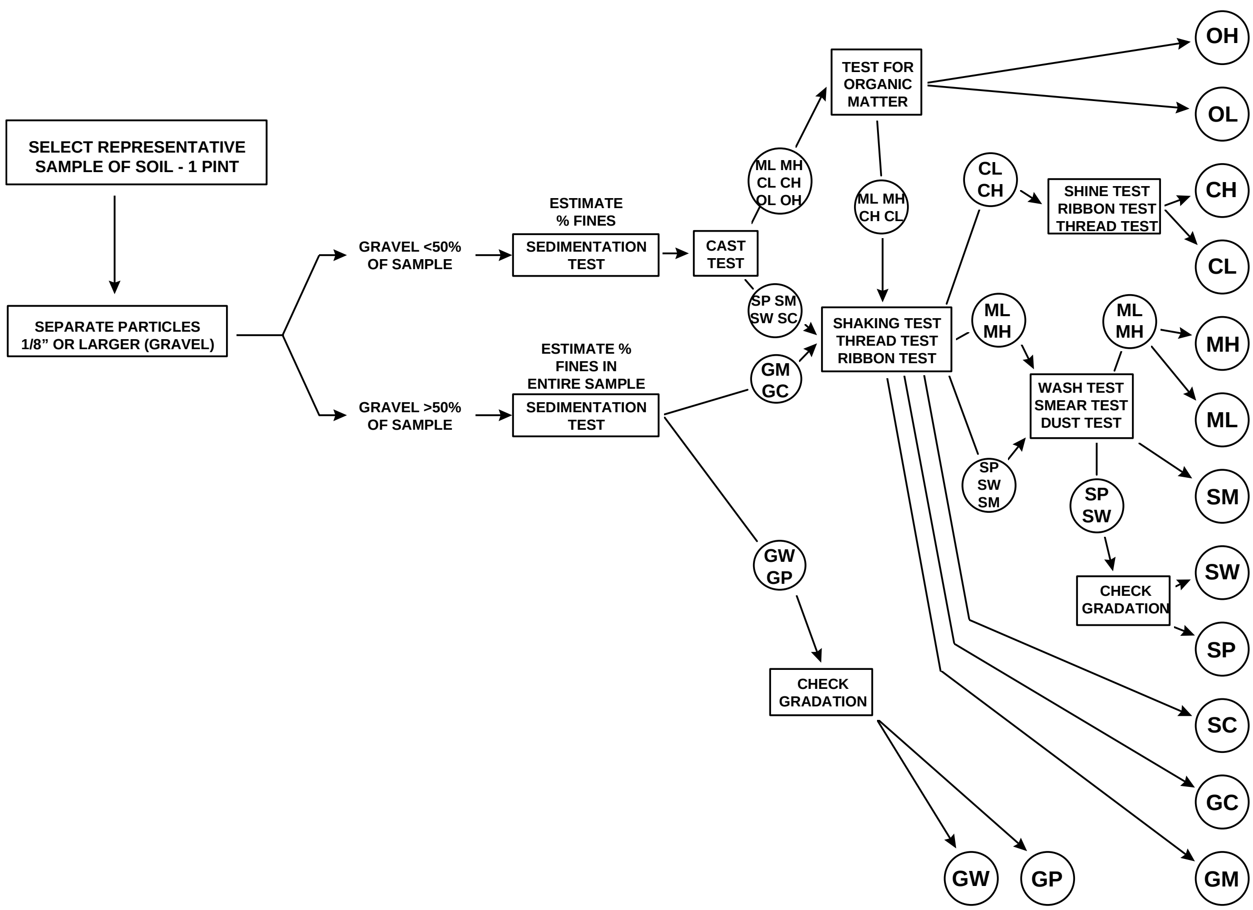


Figure A.1. Field Identification Procedures

A.2.1. Equipment Required. Field tests may be performed with little or no equipment other than a small amount of water. However, accuracy and uniformity of results will be increased by the proper use of available equipment. The following is a suggested list:

- Sieves:
  - No. 40. All tests used to identify the fine-grained portions of any soil are performed on the portion of the material which passes the No. 40 sieve. If this sieve is not available, a rough separation may be made by spreading the material on a flat surface and removing the gravel and larger sand particles.

  - No. 4. This sieve defines the limit between gravels and sands.
  - No. 200. This sieve defines the limit between sands and fines. The sedimentation test may also be used to separate the sands and fines. This test requires a transparent cup or jar.
- Pan and oven or other heating device.
- Mixing bowl and pestle.
- Scales or balances.
- Knife or small spatula.

A.2.2. Tests for Field Identification. The USCS considers three soil properties: the percentage of gravel, sand, or fines; the shape of the grain-size distribution curve; and the plasticity. The purpose of field tests is to get the best possible identification and classification in the field. Tests appropriate to a given soil sample should be made. When a simple visual examination will define the soil type, only the tests needed to verify this are necessary. When results from a test are inconclusive, some of the similar tests should be tried to establish the best identification.

A.2.2.1. Visual Examination. This test should establish the color, grain sizes, grain shapes of the coarse-grained portion, approximate gradation, and some properties of the undisturbed soil.

A.2.2.1.1. Color. Color helps in distinguishing between soil types and aids in identifying soil types. It may also indicate the presence of certain chemicals, minerals, or impurities. Color often varies with moisture content. Thus the moisture content at the time of identification should be included. Colors generally become darker as the moisture content increases and lighter as the soil dries. Some fine-grained soil (OH, OL) with dark, drab shades of brown or gray, including almost black, contain organic material. In contrast, clean, bright shades of gray, olive green, brown, red, yellow, and white are associated with inorganic soils. Gray-blue or gray-and-yellow mottled colors frequently result from poor drainage. Red, yellow, and yellowish-brown result from the presence of iron oxides. White to pink may indicate considerable silica, calcium carbonate, or aluminum compounds.

A.2.2.1.2. Grain Size. The maximum particle size of each sample should be established. This determines the upper limit of the gradation curve. Gravels range down to the size of peas. Sands start just below this size and decrease until the individual grains are just distinguishable by the naked eye. Silt and clay particles are indistinguishable as individual particles.

A.2.2.1.3. Grain Shape. The shapes of the visible particles should be determined. They may vary from sharp and angular to smooth and rounded.

A.2.2.1.4. Grain Size Distribution. An approximate identification can be made by examining a dry sample spread on a flat surface. All lumps should be pulverized until individual grains are exposed, but not broken. A rubber-faced or wooden pestle and a mixing bowl are recommended, but mashing the sample underfoot on a smooth surface will suffice for an approximate identification. Separate the larger grains (gravels and some sands) by picking them out individually. Examine the remainder of the soil and estimate the proportions of visible individual particles and the fines. Convert these estimates into percentages by weight of the total sample. If the fines exceed 50 percent, the soil is considered fine-grained (M, C, or O). If the coarse material exceeds 50 percent, the soil is coarse-grained (G or S). Examine coarse-grained soil for gradation of the particle sizes from the largest to the smallest. A good distribution of all sizes means the soil is well graded (W). Overabundance or lack of any size means the material is poorly graded (P). Estimate the percentage of the fine-grained portion of the of the coarse-grained soil for further classification. Fine-grained soils and fine-grained portions of coarse-grained soils require other tests for identification.

A.2.2.1.5. Undisturbed Soil Properties. Characteristics of the soil in the undisturbed state may be helpful in identification. The compactness of gravels or sands may be loose, medium, or dense. Clays may be hard, stiff, or soft. The ease or difficulty of sample removal should be recorded. The moisture content of the soil influences the in-place characteristics. It is helpful to know the weather just prior to and during the field evaluation to determine how the soil has or will react to weather changes. The presence of decayed roots, leaves, grasses, and other vegetable matter in organic soils produces soil which is usually dark when moist, having a soft spongy feel and a distinctive odor of rotting organic matter. The odor may be musky and slightly offensive. The odor is especially apparent in undisturbed conditions or in fresh samples. It is less pronounced as the sample is exposed to air. The odor can be made stronger by heating a wet sample.

A.2.2.2. Sedimentation Test. From visual examination it is relatively easy to approximate the proportions of gravels and sands in a soil sample. Determining the proportion of fine-grained particles is more difficult but just as important. In the laboratory and in some field testing situations, the fines may be separated from the sample using the No. 200 sieve. The sedimentation test provides an alternate field method to separate fines from the sand particles in a soil sample.

- Smaller particles will settle through water at a slower rate than large particles. Placing a small amount of the fine fraction of a soil (such as a heaping teaspoon) in a transparent cup or jar, covering it with about 5 inches of water, and agitating it by stirring or shaking will completely suspend the soil in water. With cohesive soils, it will be necessary to break up all lumps of soil before adding the water. After the soil particles have been dispersed in the water and then left, they will start to settle to the bottom, beginning with the larger sized particles, in time periods indicated in Table A.3.

Table A.3. Sedimentation Test

Approximate Time of Settlement in 5 Inches of Water	Grain Diameter (millimeters)	Differentiates
2 Seconds	0.4	Coarse Sand - Fine Sand
30 Seconds	0.072 (No. 200 Sieve)	Sand - Fines
10 Minutes	0.03	Coarse Silt - Fine Silt
1 Hour	0.01	Silt - Clay

- Since all of the particles of soil larger than the No. 200 sieve will have settled to the bottom of the cup or jar 30 seconds after the mixture has been agitated, it follows that the particles still remaining in suspension are fines. The water containing the suspended fines should be carefully poured into another container 30 seconds after agitation, more water added to the cup or jar containing the coarse fraction and the procedure repeated until the water-soil mixture becomes clear 30 seconds after mixing. The cup or jar will contain the coarse fraction of the soil and the other container will hold the fines. The water is then wicked or evaporated off and the relative amounts of fines and sands determined fairly accurately.
- In clay soils the clay particles will often form small lumps (flocculate) that will not break up in water. If after several repetitions of the test, substantial amounts of clay are still present in the coarse material, the sand will feel slippery. Further mixing and grinding with a stick will be necessary to help break up these lumps.

A.2.2.3. Plasticity Tests. Fine-grained soil particles (those passing the No. 200 sieve) are generally not classified using gradation criteria but are identified primarily by characteristics related to plasticity. In the laboratory Atterberg tests are used to define the liquid and plastic limits of the soil and classify it. Expedient field tests have been developed to determine the cohesive and plastic characteristics of soil. These field tests are performed only on material passing the No. 40 sieve, the same fraction used in the laboratory tests.

A.2.2.3.1. Breaking or Dry Strength Test

A.2.2.3.1.1. Pat Test.

- Procedure: Prepare a pat of soil about 2 inches in diameter and 1/2 inch thick by molding it in a wet, plastic state. Allow the pat to dry completely (in the sun, in an oven, or inside the engine compartment), then grasp the pat between the thumbs and forefingers of both hands and attempt to break it. If the pat breaks, try to powder it by rubbing it between the thumb and forefinger of one hand.
- Results:
  - Pat cannot be broken nor powdered by finger pressure - Very highly plastic soil (CH).
  - Pat can be broken with great effort, but cannot be powdered - Highly plastic soil (CL).
  - Pat can be broken and powdered, but with some effort - Medium plastic soil (CL).
  - Pat breaks easily and powders readily - Slightly plastic soil (ML, MH, or CL).
  - Pat has little or no dry strength and crumbles or powders when picked up - Nonplastic soil (ML or MH) or (OL or OH).

Note: Dry pats of highly plastic clays often display shrinkage cracks. Breaking the pat along such a crack may not give a true indication of the strength. It is important to distinguish between a break along such a crack and a clean, fresh break that indicates the true dry strength of the soil.

A.2.2.3.1.2. Ball Test (Alternative to Pat Test).

- Procedure: Select enough material to mold into a ball about one inch in diameter. Mold the material until it has the consistency of putty, adding water if necessary. From the molded material, make at three test specimens, 1/2 inch diameter balls. Allow the test specimens to dry in the air, sun or by artificial means, as long as the temperature does not exceed 60 degrees C. Test the strength of the material by crushing between the fingers.
- Results:
  - No strength. The dry specimen crumbles into powder with mere pressure of handling. (ML).
  - Low strength. The dry specimen crumbles into powder with some finger pressure. (ML or MH).
  - Medium strength. The dry specimen breaks into pieces or crumbles with considerable finger pressure. (MH or CL).
  - High strength. The dry specimen cannot be broken with finger pressure, but will break into pieces between the thumb and a hard surface. (CL or CH).
  - Very High strength. The dry specimen cannot be broken between the thumb and a hard surface. (CH).

Note: Natural dry lumps about 1/2 inch in diameter may be used, but do not use the results if any of the lumps contain particles of coarse sand. The presence of highly cementitious materials in the soil such as calcium carbonate may produce exceptionally high strengths.

A.2.2.3.2. Roll or Thread Test.

- Procedure: A representative portion of the sample is mixed with water until it can be molded or shaped without sticking to the fingers. This moisture content is referred to as being just below the sticky limit. Prepare a nonabsorbent rolling surface by placing a sheet of glass or heavy wax paper on a flat or level support, then shape the sample into an elongated cylinder and roll the prepared soil cylinder on the surface rapidly into a thread approximately 1/8 inch in diameter. If the moist soil rolls into a thread, it has some plasticity. The number of times it can be rolled into a thread without crumbling is a measure of the degree of plasticity. Soils that cannot be rolled are nonplastic.
- Results:
  - Soil may be molded into a ball or cylinder and deformed under very firm finger pressure without crumbling or cracking - High plasticity (CH).
  - Soil may be molded, but it cracks or crumbles under finger pressure - Medium plasticity (CL).
  - Soil cannot be lumped into a ball or cylinder without breaking up - Low plasticity (CL, ML, or MH).

- Soil forms a soft, spongy ball or thread when molded - Organic material (OL or OH).
- Soil cannot be rolled into a thread at any moisture content - Nonplastic soil (ML or MH).
- The higher the soil is on the plasticity chart, the stiffer the threads are as they dry out and the tougher the lumps are if the soil is remolded after rolling.

Note: Micaceous silts and sands can be rolled due to the flaky nature of the mica. The wet shaking test is the only way to distinguish this property.

A.2.2.3.3. Ribbon Test.

- Procedure: Prepare a soil sample as in the roll or thread test. Form a roll of soil about 1/2 to 3/4 inch in diameter and 3 to 5 inches long. Lay the roll across the palm of one hand (palm up), and starting at one end, squeeze the roll between the thumb and forefinger over the edge of the hand to form a flat unbroken ribbon about 1/8 to 1/4 inch thick. Allow the ribbon as formed to hang free and unsupported. Continue squeezing and handling the roll carefully to form the maximum length of ribbon that can be supported only by the cohesive properties of the soil.
- Results:
  - Sample holds together for a length of 8 to 10 inches without breaking - Highly plastic and highly compressive (CH).
  - Soil can be ribboned only with difficulty to 3 to 8 inch lengths - Low plasticity (CL).

A.2.2.3.4. Wet Shaking Test.

- Procedure:
  - Form a ball of soil about 3/4 inch in diameter, moistened with water to just below the sticky limit. Smooth the soil pat in the palm of the hand with a knife blade or small spatula, shake it horizontally, and strike the back of the hand vigorously against the other hand. When shaking, water comes to the surface of the sample producing a smooth, shiny, or livery appearance.
  - Squeeze the sample between the thumb and forefinger of the other hand. The surface water will disappear. The surface will become dull and the sample will become firm, resisting deformation. Cracks will occur as pressure is continued and the sample will crumble.
  - If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together.
- Results: This process can only occur when the soil grains are bulky and noncohesive. Very fine sands and silts are readily identified by this test. Even small amounts of clay will tend to retard the reaction to this test.
  - A rapid reaction is typical of nonplastic, fine sands and silts.
  - A sluggish reaction indicates slight plasticity indicating the silt has small amounts of clay or organic silts.
  - No reaction at all does not indicate a complete absence of silt or fine sand.

A.2.2.3.5. Bite or Grit Test.

- Procedure: Grind a small pinch of soil lightly between the teeth.
- Results:
  - Sandy soils. The sharp hard particles of even fine sands will grate very harshly between the teeth and will be highly objectionable.
  - Silty soils. Silt grains are not particularly gritty, but their presence is still quite unpleasant and easily detected.
  - Clayey soils. Clay grains feel smooth and powdery like flour. Dry lumps will stick when lightly touched with the tongue.

A.2.2.3.6. Shine Test.

- Procedure: Rub a clay sample with a fingernail or smooth metal surface such as a knife blade.
- Results:
  - Highly plastic clay will produce a definite shine.
  - Lean clays will remain dull.

A.2.2.3.7. Feel Test.

- Consistency. Squeeze a piece of undisturbed soil between the thumb and forefinger. It may be hard, stiff, brittle, friable, sticky, plastic, or soft. Remold the soil by working it between the hands. This can indicate the natural water content. Clays which become fluid on remolding are probably near their liquid limit. If they remain stiff and crumble, they are probably below their liquid limit.
- Texture. Rub a portion of fine-grained soil between the fingers or on a more sensitive area such as the inside of the wrist. Results are similar to the bite or grit test.

APPENDIX B

Condition Survey and Maintenance Procedures

B.1. Condition Survey Procedure

B.1.1. Introduction. During contingency or expedient operations, it is important that personnel have the ability and tools to quickly and accurately assess a pre-existing or newly constructed unsurfaced airfield and to monitor it for required maintenance. This rating system will show you how to divide the airfield into features (runway, taxiway, apron, hammerhead, and overruns) and sections, identify the distresses (problems) that exist or develop, rate the severity of each distress, and determine whether the airfield is operational or should be closed for repairs.

B.1.2. Equipment Required: Measuring wheel or 100-foot steel tape, carpenter's 6-foot folding rule, straightedge (8-foot 2´4 or other), stringline (if enough personnel are available), clipboard, inspection sheets, this appendix, and pens or pencils.

B.1.3. How the Method Works. The method for rating the condition of semi-prepared airfields has four steps:

Step 1: Divide the airfield into features and sections.
Step 2: Inspect the airfield and identify the distresses.
Step 3: Calculate the rating for each section.
Step 4: Use the ratings to determine if the airfield is

GREEN • Operational for low-risk operations

AMBER • Needs monitoring and should be repaired if possible; medium-risk operations

RED • Dangerous and must be repaired; high-risk operations

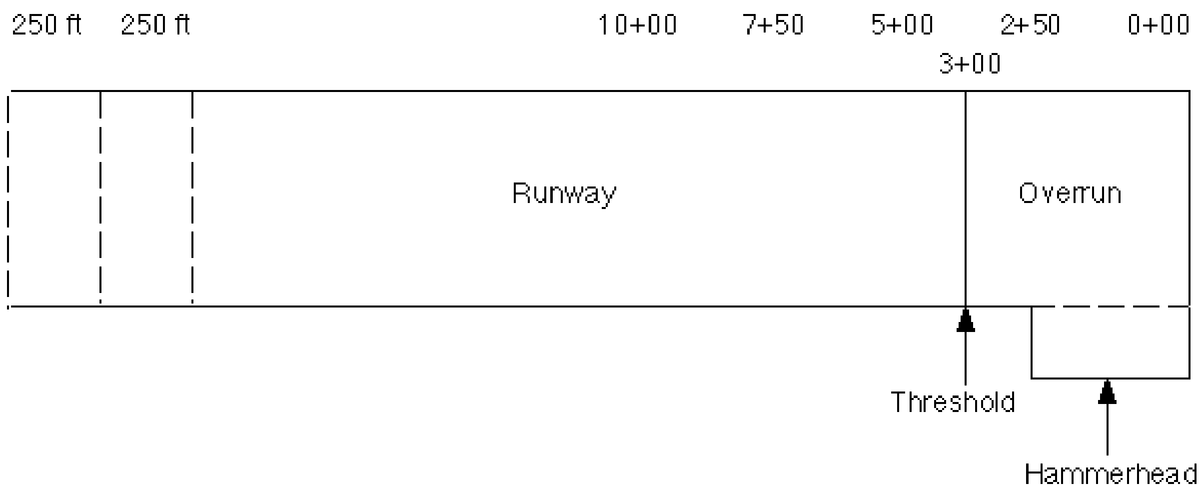
When the surface condition is rated as amber, maintenance should be performed as the mission allows. If any single distress is rated as red, the landing zone safety officer will determine the feasibility of each operation.

Inspections should increase in frequency as the condition of the airfield degrades. If the condition approaches red, inspection could be as frequent as before each operation.

STEP ONE: DIVIDING THE AIRFIELD INTO FEATURES AND SECTIONS

Before you start to inspect the airfield, divide the entire field into features and sections. This includes the runway, both overruns, any taxiways, the aprons, and the hammerheads. Each section is 250 feet long and the width of the runway or taxiway. The hammerheads and overruns should each be a section. The aprons should be divided into sections of approximately 25,000 square feet.

The starting point 0 + 00 is at the very end of the overrun. Use a rolling wheel measure or steel tape to measure distances. Mark every 250-foot point with a nail and plastic surveyor's tape with the station marked on it or use some other permanent marker along the outside edge of the runway (out of the trafficked area).



Before the runway is used for the first time, every section should be inspected to give baseline information. As a minimum for contingency operations, sections should be located in the touchdown area, in the primary braking area at approximately 1000 to 1500 feet, at the point of aircraft rotation at approximately 2000 to 2500 feet, and at the last 500 feet of the runway. (The point of rotation may move due to pressure and altitude changes.) These sections include the areas most likely to be damaged by landing, braking, stopping, acceleration, and takeoff for the runway in use. Inspect and monitor additional areas where degradation develops.

STEP TWO: INSPECTING THE AIRFIELD AND IDENTIFYING DISTRESSES

Conduct as detailed and accurate an inspection as time and conditions permit. By doing it right the first time, you will be able to identify possible problem areas and monitor them closely during operations.

There are seven possible problems or distresses. In each 250-foot section you may have no distresses or you may have as many as seven distresses. If you have trouble telling which distress you are looking at, make a reasonable guess. The system is flexible enough to give you an accurate rating. The seven distresses are:

91. Potholes
92. Ruts
93. Loose aggregate
94. Dust
95. Rolling resistant material
96. Jet blast erosion
97. Stabilized layer failure

(The numbers 91–97 are associated with the Micro-Paver Pavement Management System and will be used in the computerized version of this system.)

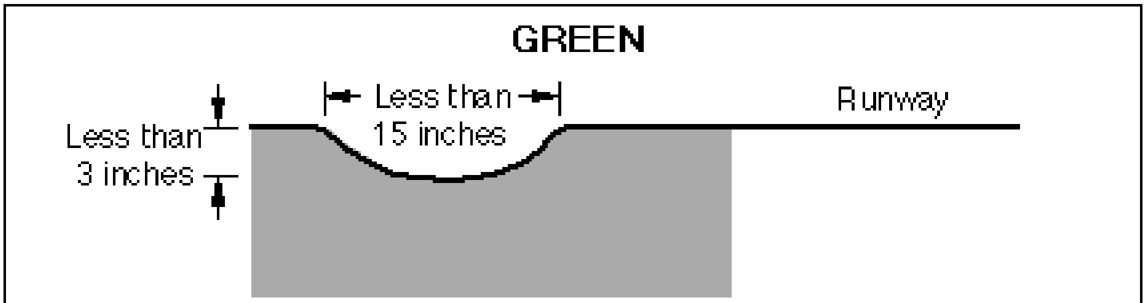
Fill in the identifying information on the top of the inspection sheet and record the severity levels on the table. The following pages will give you the definition of each distress and explain how to determine the severity level for that distress.

Unless otherwise stated, the distress severity measurements for contingency and training operations are the same.

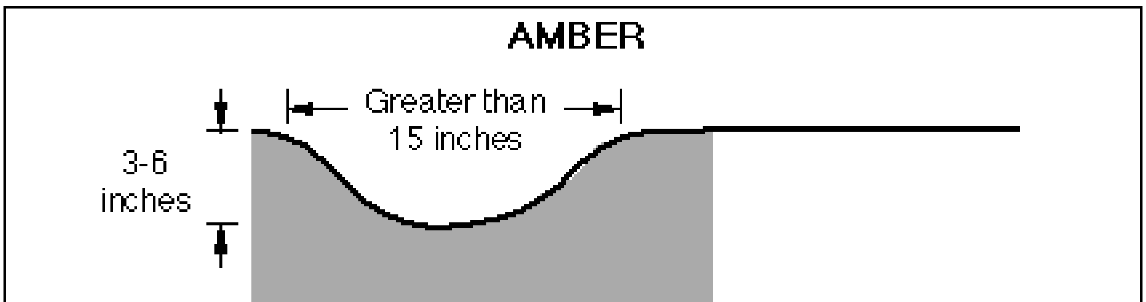
91. POTHOLES

DEFINITION: Potholes are bowl-shaped depressions in the airfield surface. Once potholes have begun to form, the runway will continue to disintegrate because of loosening surface material or weak spots in the underlying soils. NOTE: An abrupt vertical change of more than 2 inches will cause the nose gear to collapse and must be repaired before the airfield can be used.

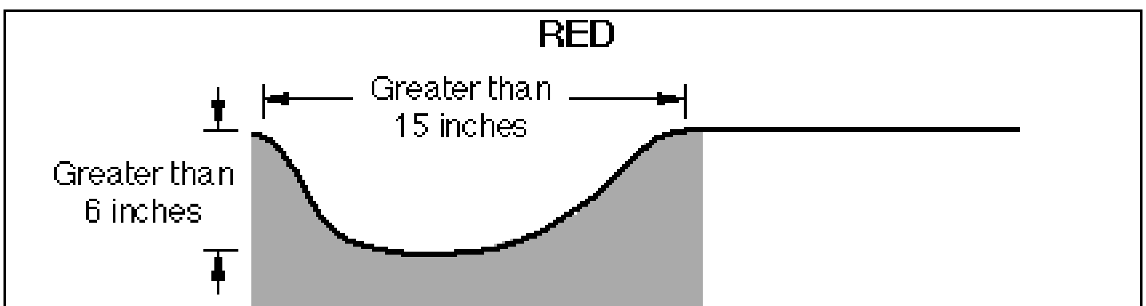
HOW TO MEASURE: Measure the depth of the biggest potholes and determine their severity level. In areas of high pothole density, observe aircraft reaction. The location and number of potholes can be critical to aircraft performance.



Potholes are less than 3 inches deep and/or less than 15 inches in diameter.



Potholes are 3-6 inches deep and greater than 15 inches in diameter.



Potholes are greater than 6 inches deep and greater than15 inches in diameter.

SEMI-PREPARED AIRFIELD INSPECTION SHEET
FOR C-17 OPERATIONS

Airfield Bicycle Lake Date 4/17/97
Section 17+50 – 20+00 Inspector Kent Shepherd

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G							
	A	✓						
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value	REMARKS

RATING

G	A	R

Total deduct value =
q =
SPACI =

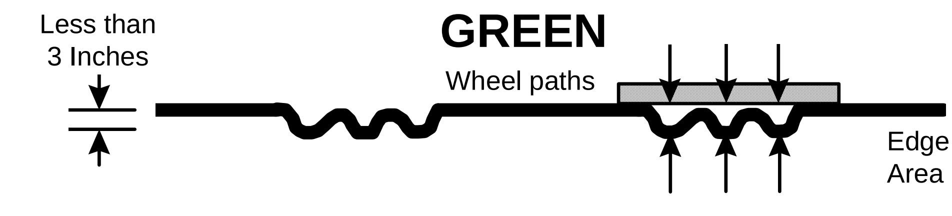
NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

Potholes, Amber Severity

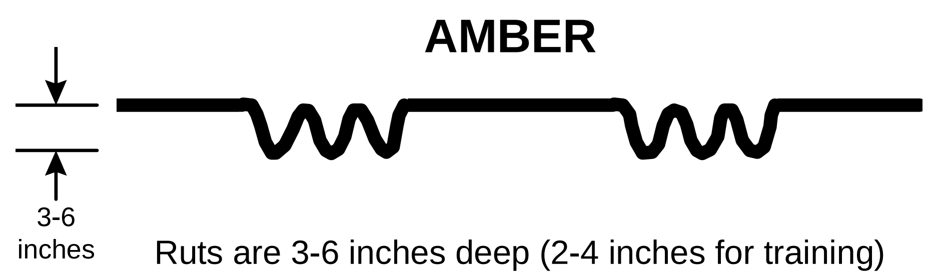
92. RUTS

DEFINITION: Ruts are surface depressions in the wheel paths that run parallel to the centerline. They result from repeated aircraft passes and become more severe with time.

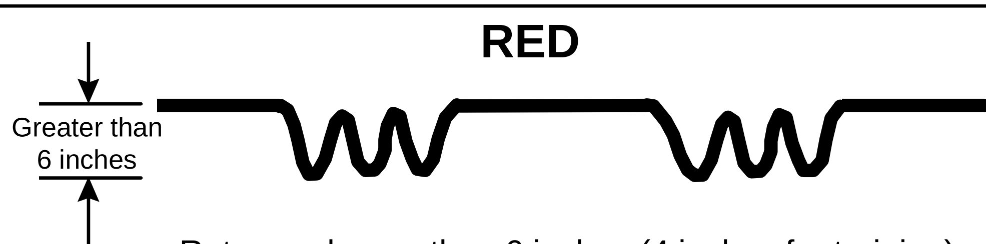
HOW TO MEASURE: Lay a straightedge across the ruts with both ends resting on the solid runway surface with loose (rolling resistant material) removed. Measure the average depth of the three deepest ruts on each side, from the bottom of the straightedge to the solid ground in the bottom of the rut. Use the higher average (left or right) depth for that location. Rut width does not affect severity.



Ruts exist but are less than 3 inches deep (2 inches for training)



Ruts are 3-6 inches deep (2-4 inches for training)



Ruts are deeper than 6 inches (4 inches for training)

SEMI-PREPARED AIRFIELD INSPECTION SHEET
FOR C-17 OPERATIONS

Airfield Bicycle Lake   Date 4/17/97
Section 17+50 — 20+00   Inspector Jim Greene

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G		✓					
	A							
	R							

SPACI CALCULATIONS

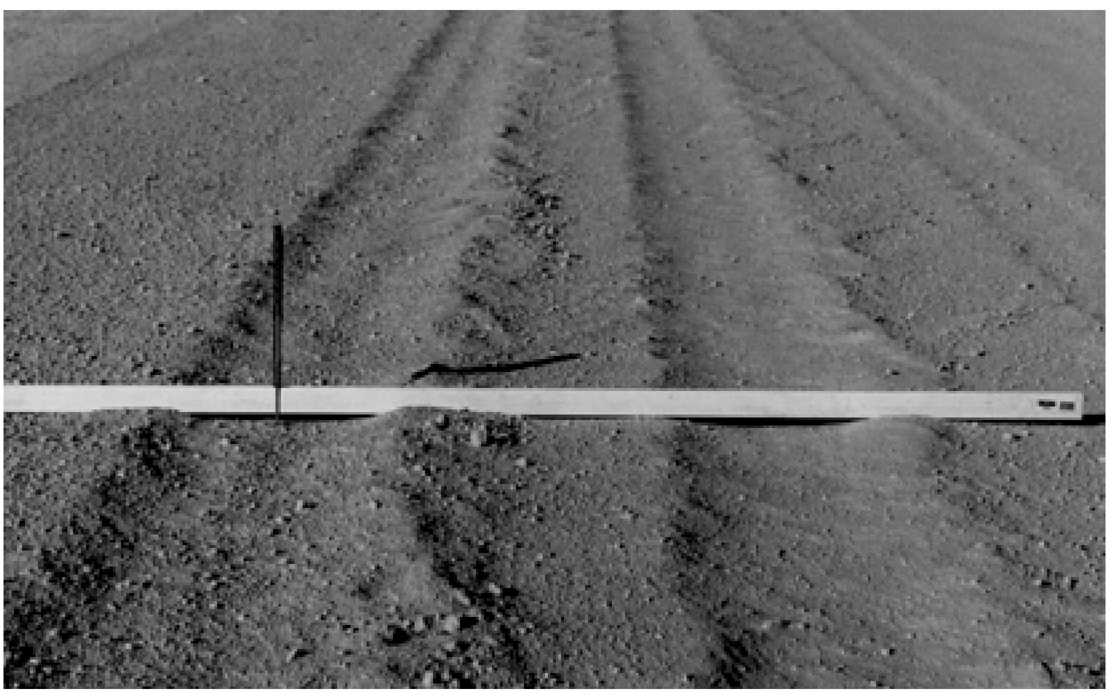
Distress Type	Severity	Deduct Value	REMARKS

RATING

G	A	R

Total deduct value =
q =
SPACI =

NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.



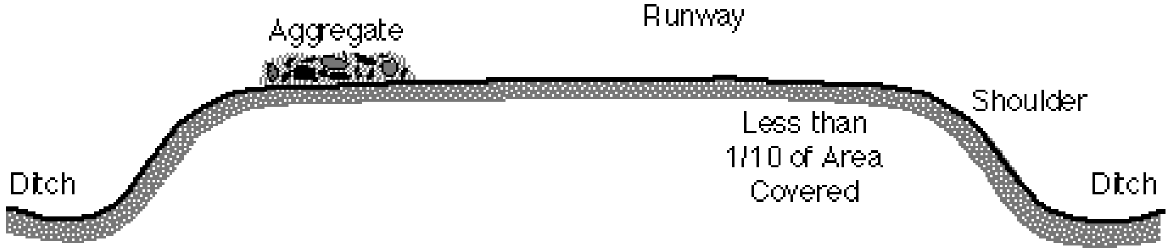
Ruts, Green Severity

93. LOOSE AGGREGATE

DEFINITION: Loose aggregate consists of small stones ¼-inch or larger that have separated from the soil binder. In large enough quantities and sizes, it becomes dangerous. Rocks over 4 inches in diameter must be removed from the airfield before any operations. If material crushes underfoot, it is not considered loose aggregate.

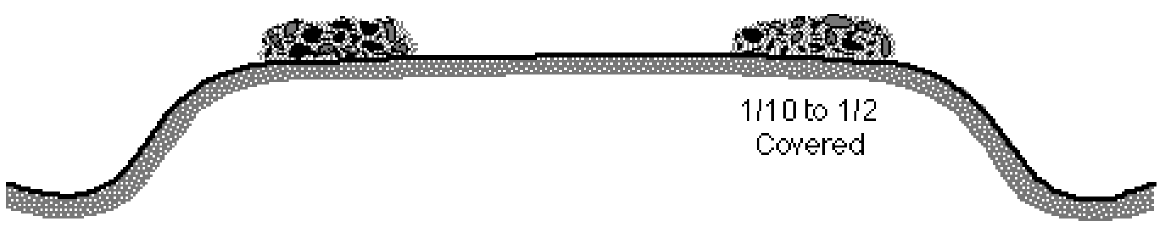
HOW TO MEASURE: Estimate the area of the section that is covered by loose aggregate and check the appropriate box in the severity table.

GREEN



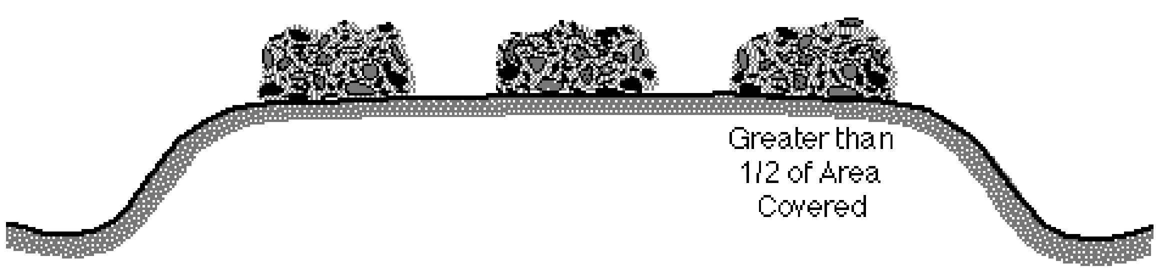
Loose aggregate exists but covers less than 1/10 of the section.

AMBER



Between 1/10 and 1/2 of the section has loose aggregate exposed and lying on the surface.

RED



More than 1/2 of the section has loose aggregate covering the surface.

SEMI-PREPARED AIRFIELD INSPECTION SHEET
FOR C-17 OPERATIONS

Airfield Bicycle Lake Date 4/17/97
Section 17+50 — 20+00 Inspector John Hoffman

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G							
	A			✓				
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value	REMARKS

RATING

G	A	R

Total deduct value =
q =
SPACI =

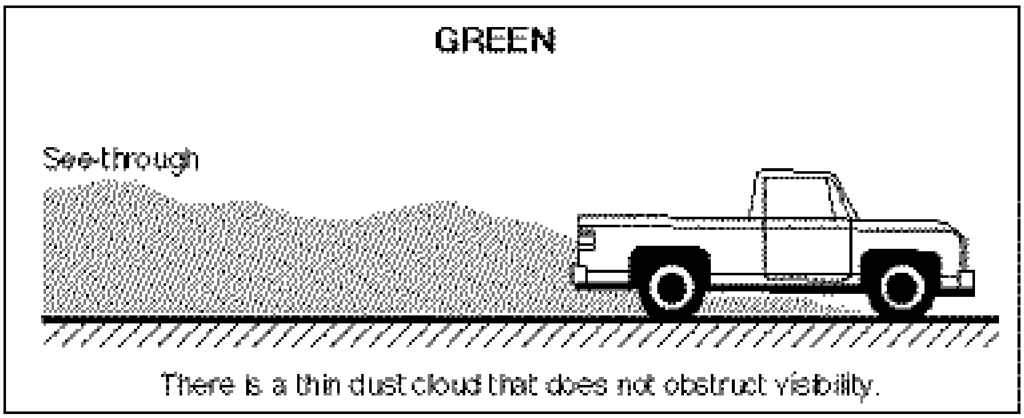
NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

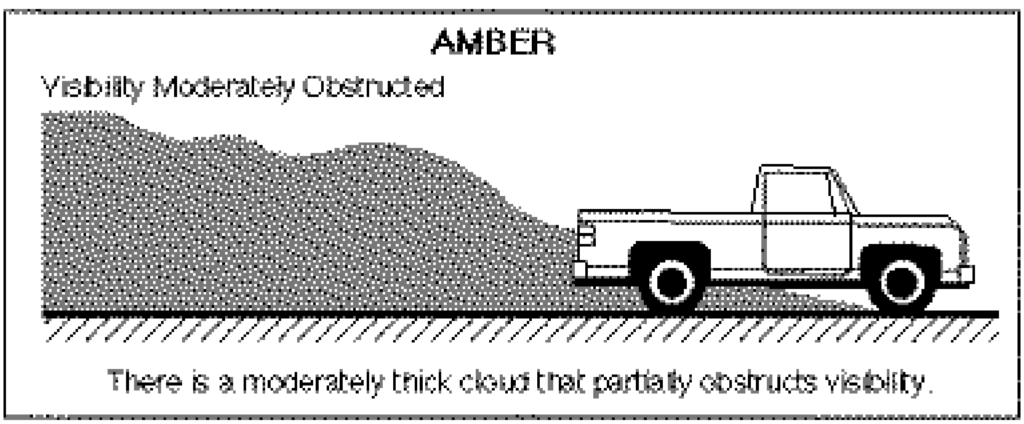
Loose Aggregate, Amber Severity

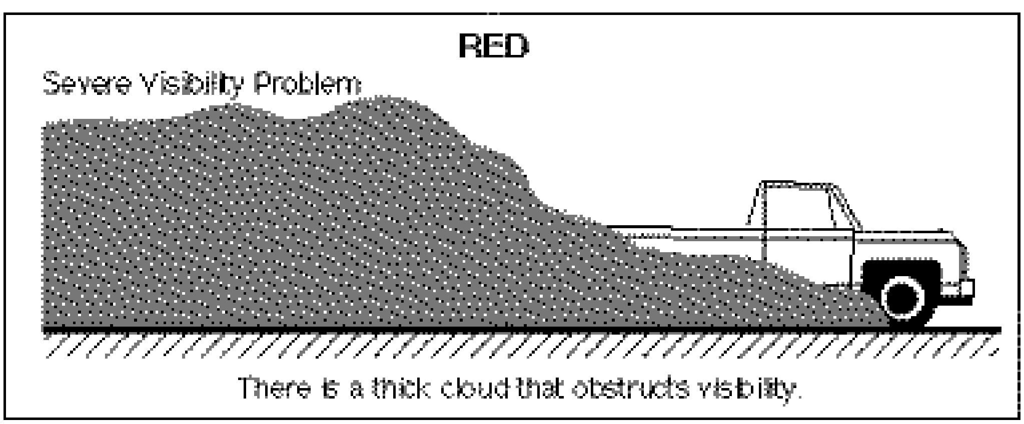
94. DUST

DEFINITION: Dust is fine material that becomes airborne when disturbed. The natural material on unsurfaced airfields and the multiple passes of the aircraft cause these fine materials to separate from the soil binder and become a significant problem for personnel, trailing aircraft, and the environment.

HOW TO MEASURE: Have a vehicle drive at 60 miles per hour down the runway. Watch the dust cloud and check the appropriate box on the table. For example, if you cannot see the vehicle, check Red.







SEMI-PREPARED AIRFIELD INSPECTION SHEET
FOR C-17 OPERATIONS

Airfield Bicycle Lake   Date 4/17/97
Section 17+50 - 20+00   Inspector Steve Bales

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G							
	A							
	R				✓			

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value	REMARKS

RATING

G	A	R

Total deduct value =
q =
SPACI =

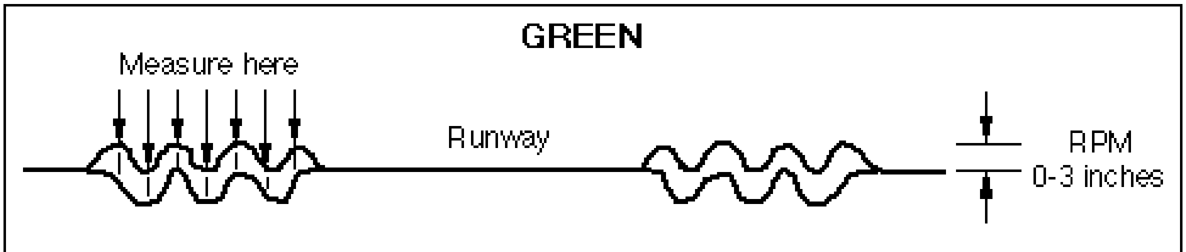
NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

Dust, Red Severity

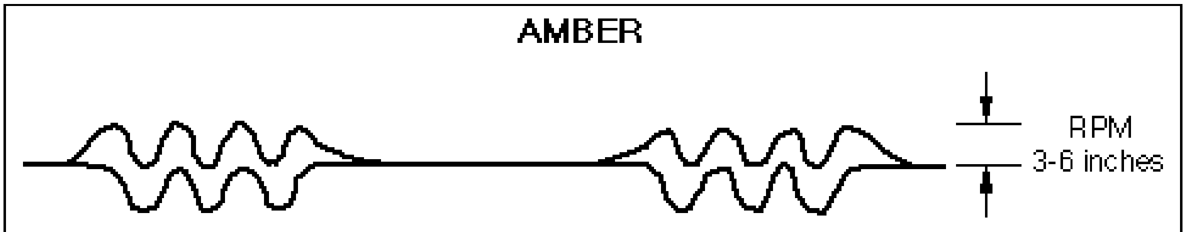
95. ROLLING RESISTANT MATERIAL

DEFINITION: Rolling resistant material (RRM) is any type of loose or unbound material that separates from the solid base and lies on top of the surface and in the ruts. In sufficient quantities, it increases the rolling resistance, and therefore increases the amount of runway required for C-17 takeoffs. It is more prevalent in dry soils and is a byproduct of severe rutting.

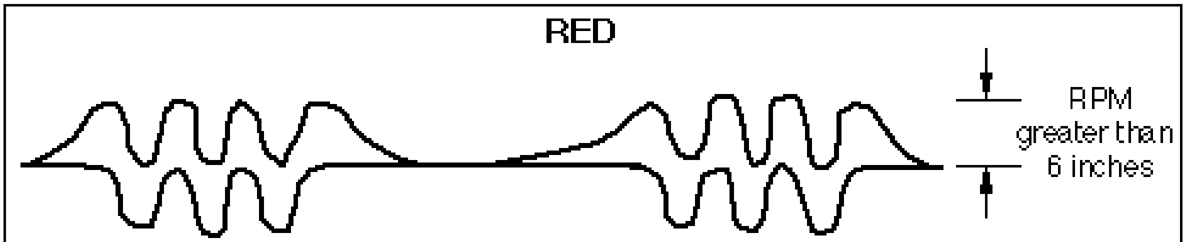
HOW TO MEASURE: Stick a ruler into the RRM until you hit solid ground and read the number on the ruler at the top of the RRM to the nearest ¼ inch. Take a minimum of seven measurements in each gear path and average those measurements. Determine average RRM depth by averaging the measurements in the touchdown area, in the primary braking area, at the point of rotation, and the last 500 feet of runway. For a typical 4000-foot runway, take one set of measurements at approximately 5 + 00, 10 + 00, 20 + 00, and 35 + 00.



RPM exists but is less than 3 inches deep (2 inches for training).



RPM is 3-6 inches deep (2-4 inches for training).



RPM is greater than 6 inches deep (4 inches for training).

SEMI-PREPARED AIRFIELD INSPECTION SHEET FOR C-17 OPERATIONS

Airfield Bicycle Lake Date 4/17/97
Section 17+50 - 20+00 Inspector B. J. Skar

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G							
	A					✓		
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value	REMARKS

RATING

G	A	R

Total deduct value =
q =
SPACI =

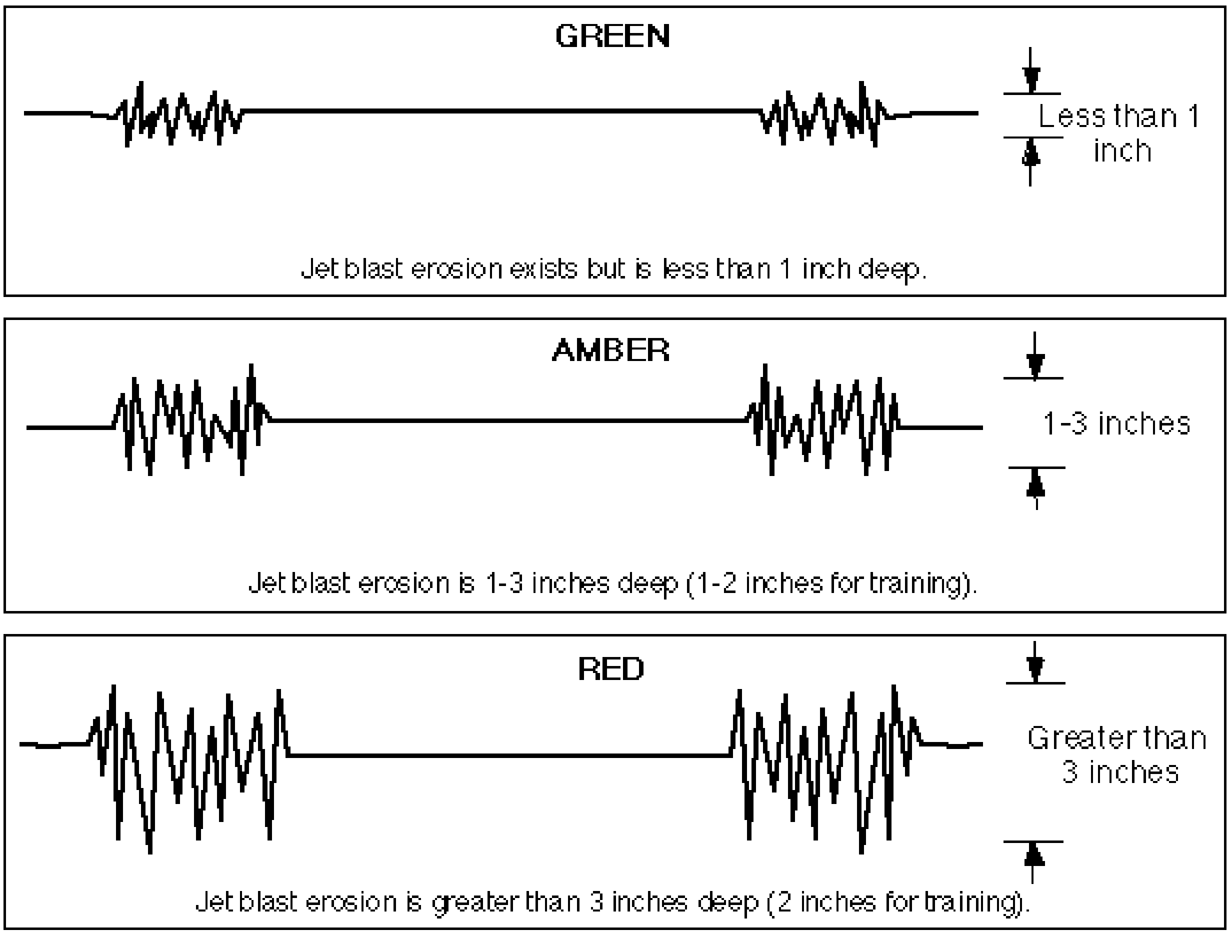
NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

RPM, Amber Severity

96. JET BLAST EROSION

DEFINITION: Jet blast erosion occurs when the top layer of soil is blown or stripped away in the areas that are scoured by the C-17 engines as they fire up to taxi or take off. Jet blast erosion outside trafficked areas can be ignored. Jet blast erosion in trafficked areas must be maintained. Jet blast erosion is characterized by no evidence of loose aggregate.

HOW TO MEASURE: Measure the depth of the erosion and check the appropriate box on the inspection sheet.



SEMI-PREPARED AIRFIELD INSPECTION SHEET FOR C-17 OPERATIONS

Airfield Bicycle Lake Date 4/17/97

Section 17+50 – 20+00 Inspector Bruce Fox

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G						✓	
	A							
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value	REMARKS

RATING

G	A	R

Total deduct value =

q =

SPACI =

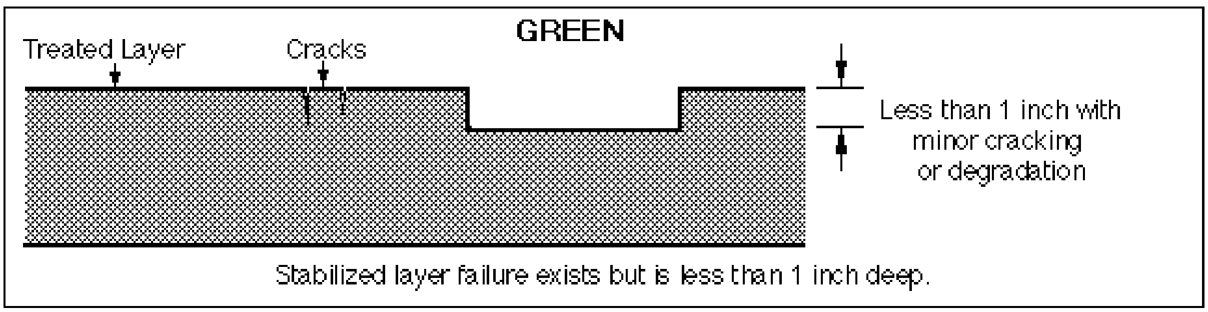
NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

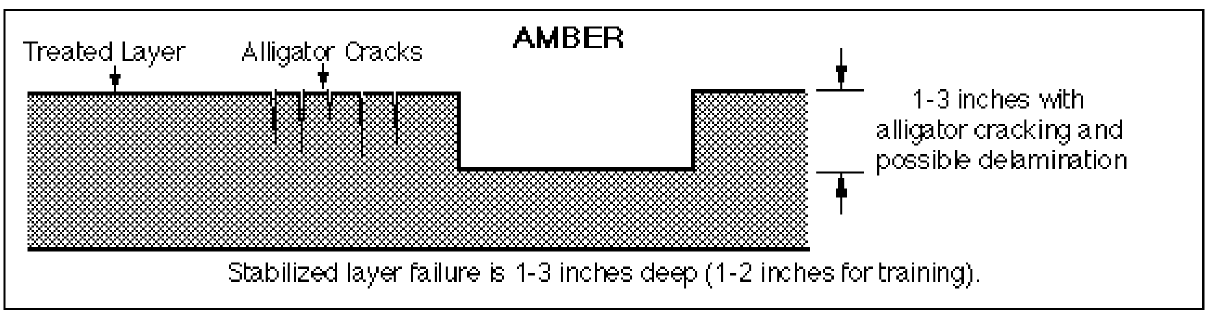
Jet Blast Erosion, Green Severity

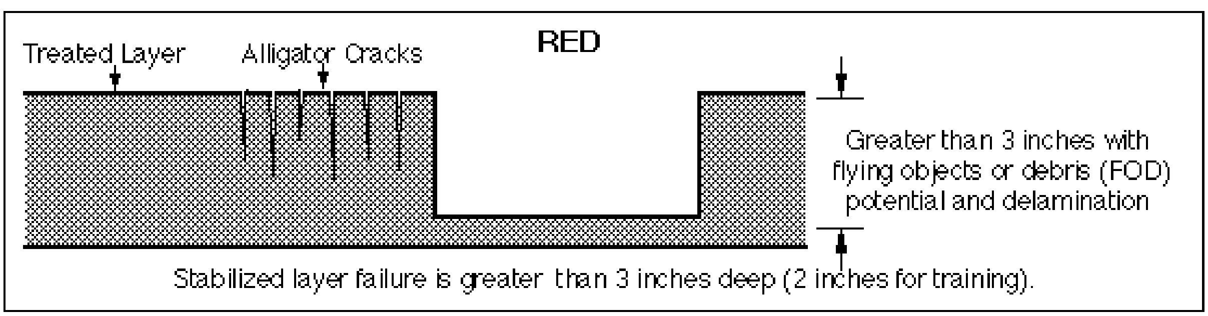
97. STABILIZED LAYER FAILURE

DEFINITION: If the runway surface material is mixed with a stabilizing agent, such as Portland cement, the resulting mix is called a stabilized layer. A failure occurs when areas of that layer begin to crack and delaminate. It is a progressive failure. The number and size of cracks increase, layers can delaminate, and pieces can be removed. The cracks get closer together and interconnect until the surface resembles an alligator skin; this is called alligator cracking and usually indicates weak support beneath. NOTE: An abrupt vertical change of more than 2 inches will cause the nose gear to collapse. The runway surface must be repaired before the airfield can be used.

HOW TO MEASURE: Put a straightedge across the failed area and measure the depth.







(15 October 1997)

SEMI-PREPARED AIRFIELD INSPECTION SHEET
FOR C-17 OPERATIONS

Airfield Holland Date 6/17/97
Section 40+00 – 42+50 Inspector Jack LeBrun

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G							
	A							✓
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value

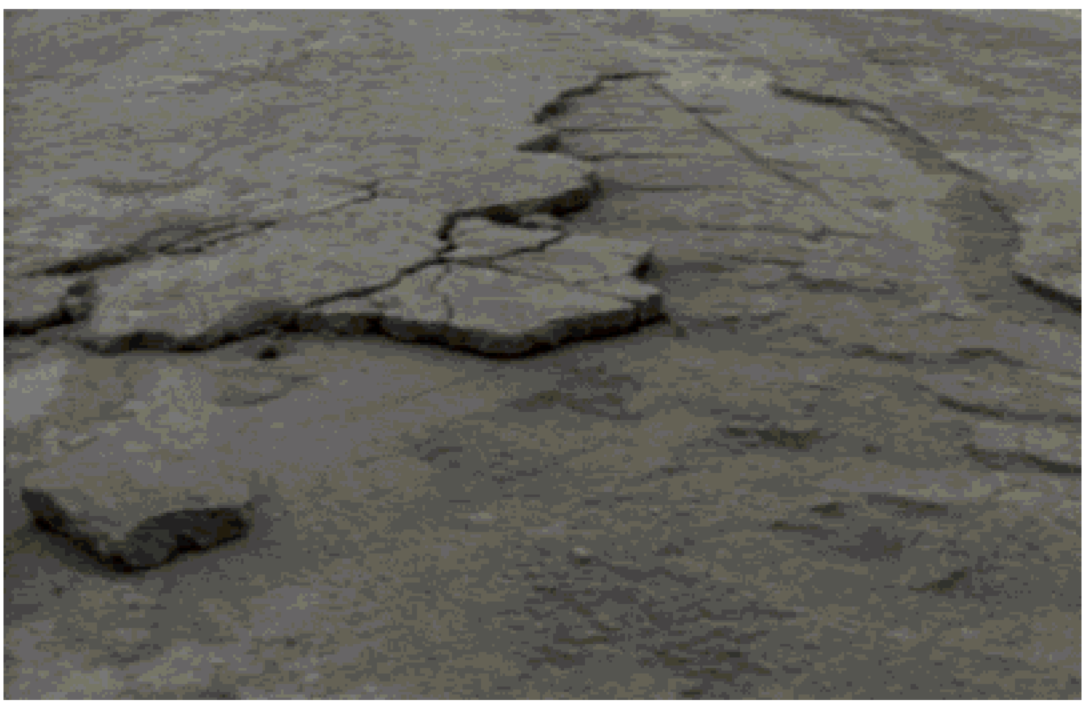
REMARKS

RATING

G	A	R

Total deduct value =
q =
SPACI =

NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.



Stabilized Layer Failure, Amber Severity

Atch 1
(71 of 164)

STEP THREE: CALCULATING THE RATINGS

The distress measurements are used to calculate the Semi-Prepared Airfield Condition Index (SPACI), based on deduct values. A deduct value is a number from 0 to 100, with 0 meaning that the distress has no impact on the airfield condition and 100 meaning that the airfield has completely failed. Deduct values for runways and taxiways where the aircraft is moving are different than those on aprons and hammerheads where the C-17 may be offloading equipment. The deduct value table reflects these differences. We will show how to do this calculation by running through an example.

1. Fill in the identifying information at the top of the inspection sheet.
2. Put a check mark in the severity box corresponding to the distresses you find. If you don't find some distresses, leave those boxes blank.
3. Refer to the "Table of Deduct Values for C-17 Operations " on page 77. Each distress has a deduct value for each severity level.
4. For potholes of Green severity on the runway, the deduct value is 4.
5. Record that number in the correct box on the bottom left side of the inspection sheet.
6. For ruts at Amber severity, the deduct value is 18.
7. For loose aggregate at Amber severity, the deduct value is 6.
8. For dust at Amber severity, the deduct value is 4.
9. Add all the distress values and record the total on the line labeled "Total deduct value." In this case, the total deduct value is 32.
10. Count the total number of distresses that have deduct values greater than 5. That is the *q* alue. Record it on the line labeled *q*. For this example, *q* is 2.
11. On the SPACI curve (page 77), locate the "Total Deduct Value." Go across the numbers on the bottom of the graph until you reach the total deduct value of 32.
12. Go up the vertical line until it intersects with the curved line that matches your *q* number (in this example, 3). From that point, follow the line across to the left to find the rating (the SPACI). For this example, the SPACI is 77.
13. Go to the SPACI scale (page 77), which shows that 77 is in the Green range.
14. Circle this overall rating on the bottom left of the inspection sheet.
15. This is the rating for this section. The rating for the runway is the average of the ratings from all the sections. For example, SPACIs of 63, 59 and 67

in different sections would give an average SPACI of 63 for the whole runway.

NOTE:

If any distress is Red, the landing zone safety officer will determine the feasibility of each operation.

SEMI-PREPARED AIRFIELD INSPECTION SHEET FOR C-17 OPERATIONS

Airfield Alamo, NV Date 4/30/97

Section 10+00 – 12+50 Inspector Bob Eaton

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G	✓						
	A		✓	✓	✓			
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value
91	G	4
92	A	18
93	A	6
94	A	4

Total deduct value = 32

q = 2

SPACI = 77

RATING

G	A	R

REMARKS

NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

SEMI-PREPARED AIRFIELD INSPECTION SHEET FOR C-17 OPERATIONS

Airfield Alamo, NV Date 4/30/97

Section 10+00 – 12+50 Inspector Renee Melendy

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

SKETCH

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G	✓	✓			✓		
	A				✓			✓
	R						✓	

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value
91	G	4
92	G	14
94	A	4
95	G	18
96	R	15
97	A	10

Total deduct value = 65

q = 4

SPACI = 61

RATING

G	A	R

REMARKS

NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

SEMI-PREPARED AIRFIELD INSPECTION SHEET FOR C-17 OPERATIONS

Airfield Alamo, NV   Date 4/30/97

Section 10+00 - 12+50   Inspector John Severance

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G	✓						
	A				✓			✓
	R						✓	

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value
91	G	4
94	A	4
96	R	15
97	A	10

Total deduct value = 33

q = 2

SPACI = 76

RATING

G	A	R

REMARKS

NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

SEMI-PREPARED AIRFIELD INSPECTION SHEET
FOR C-17 OPERATIONS

Airfield ______________________ Date ______________________

Section ______________________ Inspector ______________________

SKETCH

DISTRESS TYPES

91. Potholes
92. Ruts
93. Loose Aggregate
94. Dust
95. Rolling Resistant Material
96. Jet Blast Erosion
97. Stabilized Layer Failure

DISTRESS SEVERITY

Type		91	92	93	94	95	96	97
Severity	G							
	A							
	R							

SPACI CALCULATIONS

Distress Type	Severity	Deduct Value	REMARKS
RATING	Total deduct value =		
	q =		
	SPACI =		

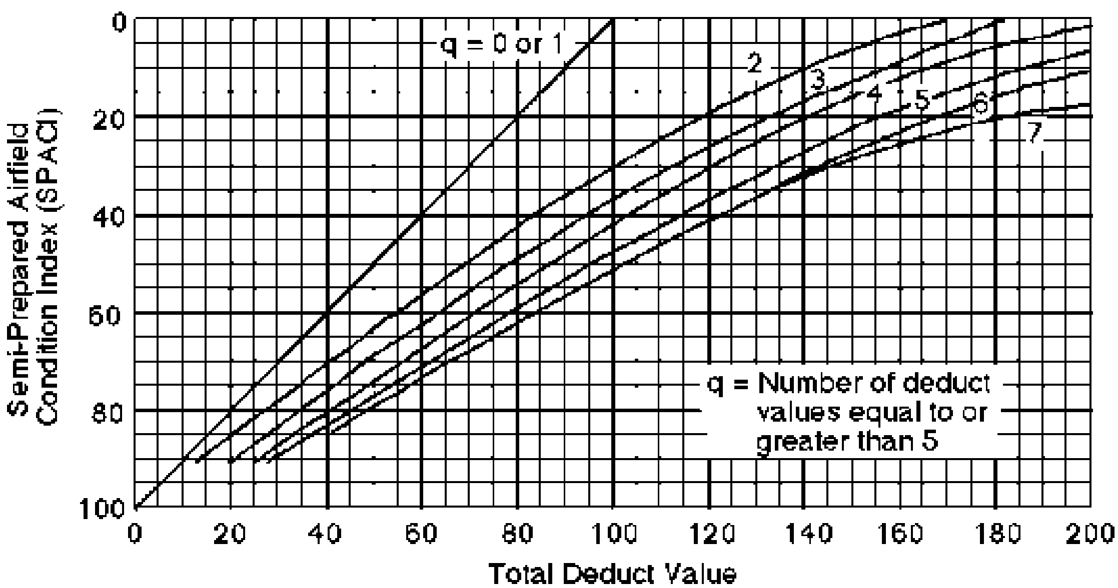
G	A	R

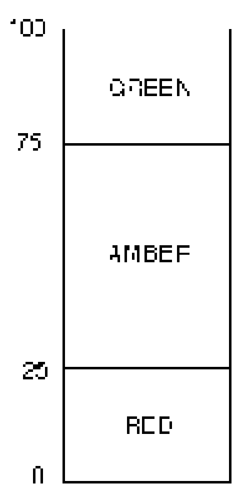
NOTE: If any distress is red, the landing zone safety officer will determine the feasibility of each operation.

Deduct Values for C-17 Contingency Operations

	Distress	Green		Amber		Red	
		R/T*	H/A**	R/T	H/A	R/T	H/A
91	Potholes	4	2	10	6	20	12
92	Ruts	14	4	18	6	24	10
93	Loose Aggregate	4	15	6	30	8	45
94	Dust	2	15	4	30	6	45
95	Rollling Resistant Material	18	2	22	4	26	15
96	Jet Blast Erosion	5	10	10	30	15	40
97	Stabilized Layer Failure	5	15	10	25	15	35

*R/T – runways and taxiways
**H/A – hammerheads and aprons





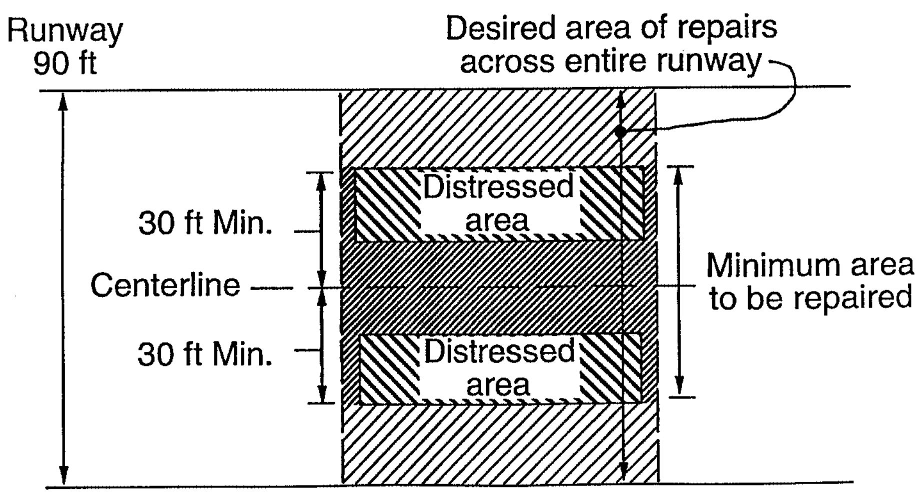
SPACI Scale

B.2. Maintenance Procedures. Maintenance on semi-prepared airfields will be determined by:

- Equipment available
- Materials available
- Time available.

For all distresses except potholes, the BEST procedure is to rework or reconstruct the entire distressed area from runway shoulder to runway shoulder. The MINIMUM requirement is to rework or reconstruct from the outside of the main landing gear path across the runway centerline to outside the opposite main landing gear path (outside of distressed area to outside of distressed area, minimum of 30 feet both sides of the centerline to include all of the distressed area). If this course of action is selected, scarify diagonally to the direction of travel of the landing gear. This will help to distribute the load across the repair area. **Doing just the minimum can create areas of different compaction and density, which may adversely affect C-17 landings and takeoffs.**

RECOMMEND MAINTENANCE BE PERFORMED ACROSS THE ENTIRE RUNWAY IN THE AREA OF DISTRESS.



B.2.1. Soil Compaction. In contingency situations, supplemental materials may not be available to blend with or replace existing inadequately graded soils, but on-grade compaction of soil with suitable equipment can sometimes increase the soil stability and strength. This is especially true for granular soils. Improvement achieved by compaction depends upon the soil type, moisture content, and degree and method of compaction. Different soils require different compaction equipment. In general, fine-grained soils should be compacted with rubber-tired, sheepsfoot, or segmented pad rollers, and in some cases, steel wheel rollers. Vibratory rollers are well suited for coarse-grained soils and for some *dry* fine-grained soils.

B.2.2. Cohesive Soils. Cohesive soils contain enough soil fines to make the soil sensitive to changes in moisture content. They include all types of clays, silts, and clayey and silty sands and gravels, such as CH, CL, MH, ML, SC, SM, GC, and GM. For a given compactive effort and method of compaction, there is an optimum moisture content which results in the maximum dry density of the soil. At any other moisture content, the resulting soil dry density will be less for the same compactive effort. Compact cohesive soils at or slightly higher than the optimum moisture content, except when using a vibratory roller. Rubber-tired and sheepsfoot rollers are most effective for compacting cohesive soils. A towed sheepsfoot with a contact pressure of 400–600 psi or a 35- to 50-ton rubber-tired roller with four wheels will usually yield satisfactory results. Vibratory rollers are effective on some cohesive soils, particularly those containing granular fractions such as SC, SM, GC, and GM. Use steel wheel rollers to seal the surface of cohesive soils to decrease rainfall penetration.

B.2.3. Cohesionless Soils. These soils are relatively clean sands and gravels, not highly moisture sensitive and relatively pervious. They include SW, SP, GW, and GP soil types. Optimum moisture content and maximum dry density may need to be considered depending upon the type and quantity of soil fines. If a granular soil contains essentially no fines, optimum density can be achieved when the soil is almost saturated. Cohesionless soils often require continuous wetting during compaction to prevent bulking. These soils can be compacted most effectively by vibratory rollers with a total drum force of 15–20 tons. Rubber-tired rollers are somewhat less effective. Steel wheel rollers are normally used to obtain a smooth finish surface.

B.2.4. Compaction Method. The choice of compaction equipment should depend upon soil type and moisture content. Equipment should be tracked over the material at least four times, both parallel and perpendicular to the centerline of the runway. Trafficking should continue until no further densification of the material can be observed. If additional passes do not increase soil strength, the material is probably too dry or too wet. Pumping of the material in front of the roller also indicates the material is too wet.

B.2.5. Equipment Sizes. Sizes referenced in paragraphs B.2.2 and B.2.3 should provide adequate compaction to depths of 6–9 inches. If the available compaction equipment is smaller, the soil must be compacted in thinner lifts with more passes, until no further densification of the material can be observed on each lift.

B.2.6. Repairs. Passes should begin on the outside of the repair adjacent to the existing adequate surface, and should proceed toward the center of the repair. Passes should overlap, and the equipment should "crawl," rather than race, across the surface.

B.2.7. Soil Testing. Where time or available equipment precludes moisture/density tests to confirm compaction, dynamic cone penetrometer (DCP) tests should be performed following compaction to determine if the material is strong enough to support aircraft operations.

91. POTHOLES

1. Cut to at least 2 inches below the base of the pothole and at least 2 feet around the hole.
2. Add material identical to the surrounding material. This is especially important if the soil is stabilized.
3. Wet as required to obtain the optimum water content.
4. Compact to obtain the optimum density.
5. Lift thickness may have to be reduced to 2- to 3-inch lifts to obtain the optimum density depending on the compaction equipment available.

92. RUTS

1. Wet if dry.
2. Scarify.
3. Add material as required.
4. Rewet if necessary.
5. Grade to a proper cross-section.
6. Rewet as required.
7. Compact to a required optimum density.
8. Repeat 5, 6, and 7 in 2- to 3-inch lifts if needed to achieve the optimum density with the compaction equipment available.

93. LOOSE AGGREGATE

1. Wet if dry.
2. Scarify if conditions are severe.
3. Rewet as needed.
4. Add material if necessary.
5. Rescarify if material is added.
6. Rewet as needed.
7. Grade to a proper cross-section.
8. Compact to the optimum density.
9. Wet and compact again if necessary to obtain the optimum density with the compaction equipment available.

94. DUST

1. Wet as needed.
2. Use a dust palliative.
3. Stabilize if time and resources are available.
4. Install matting if required by the mission.

95. ROLLING RESISTANT MATERIAL

1. Wet.
2. Scarify.
3. Rewet as needed.
4. Grade to a proper cross-section.
5. Rewet as needed.
6. Compact to obtain the optimum density.
7. Repeat 5 and 6 in lifts if necessary to obtain the optimum density with the compaction equipment available.

96. JET BLAST EROSION

1. Wet if dry.
2. Scarify to include the undisturbed area to ensure good adhesion or bonding of the repair.
3. Rewet and add material if necessary.
4. Rescarify if material is added.
5. Grade to a proper cross-section.
6. Rewet as needed.
7. Compact to obtain the optimum density.
8. Repeat steps 6 and 7 if necessary to obtain the optimum density with the compaction equipment available.

97. STABILIZED LAYER FAILURE

Procedure One

1. Determine the stabilizing additive and amounts.
2. Pulverize.
3. Add material if necessary.
4. Obtain optimum moisture content.
5. Add the identical stabilizing additive.
6. Mix the materials. Be sure to scarify at least 2 inches into the existing stabilized material to achieve a proper cold joint both below and around the repair area.
7. Grade to a proper cross-section.
8. Add additional water if necessary to obtain optimum moisture content.
9. Grade and compact, in lifts, to obtain the optimum density.*
10. Check the cold joints for proper adhesion, with a pneumatic roller if available.
11. If failure is evident, repeat steps 6–10.

Procedure Two

1. Remove all failed material.
2. Mix up repair stabilized material on site.
3. Follow procedure in TM 5-822-7, Appendix D, page D-11.

*See TM 5-822-7, Appendix D, page D-11 for specific guidance.

APPENDIX C

Structural Evaluation Procedures for Contingency Operations

C.1. Introduction. This appendix presents the basic criteria and procedures used to determine the structural suitability or load bearing capability of an airfield to sustain C-17 contingency operations. Appropriate evaluation charts are included. This appendix does not address the geometric characteristics of an airfield such as: runway length and width, gradient criteria, or airfield and airspace clearances.

C.1.1. The HQ AFCESA Pavement Evaluation Team is tasked to assess the suitability of airfields for projection of U S forces in support of regional conflicts or stability and support operations. Other Air Force units such as Red Horse Squadrons and Special Tactics Teams (STTs) are also tasked to perform contingency evaluations of semi-prepared airfields. These taskings have increased substantially in recent years and have highlighted the need to ensure those tasked are sufficiently trained and to standardize evaluation procedures.

C.1.2. The procedures presented here (see Figure C.1) are those required to adequately evaluate an airfield. In cases where in-the-field evaluation time is limited and judgments must be made on limited available data, the reliability of the evaluation is questionable. Sound judgment must be used in reporting airfield suitability in such situations. If evaluation results indicate the airfield will not support the intended pass or load levels, refer to Section 4, Structural Design Criteria, to determine upgrade requirements.

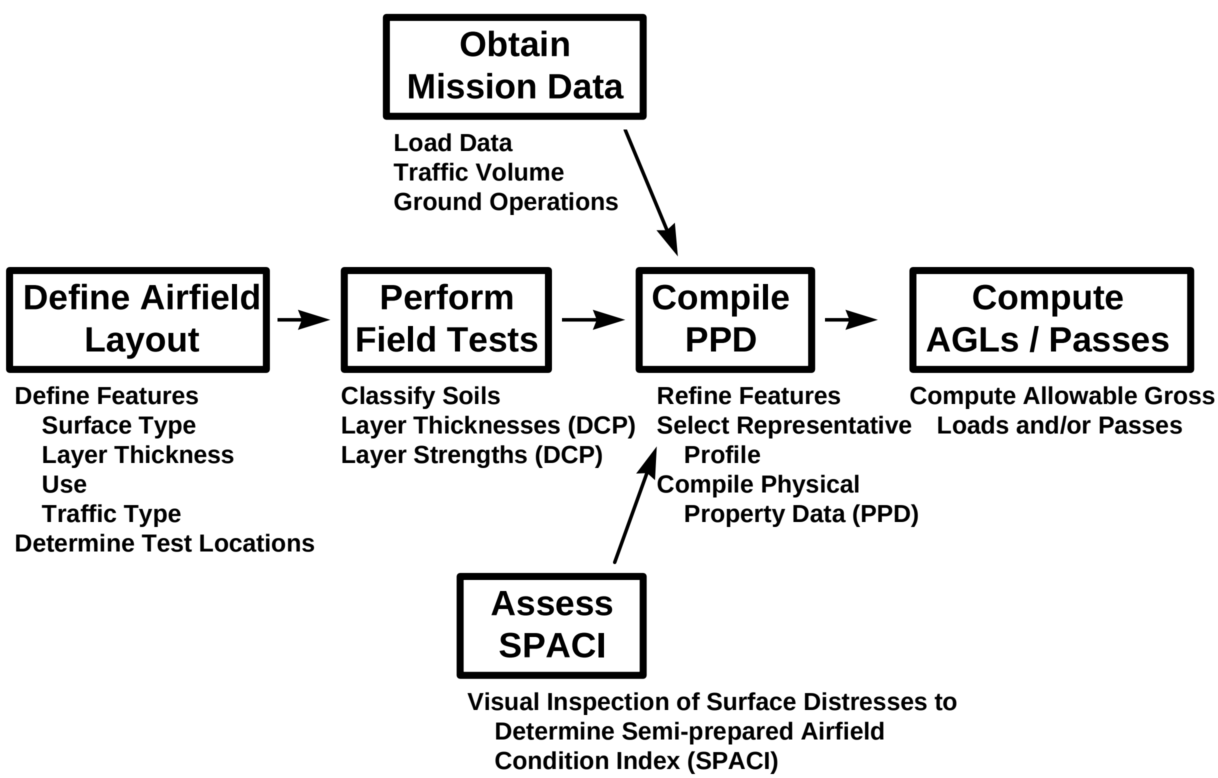


Figure C.1. Evaluation Procedures

C.1.3. If questions arise in the field, one of the following should be contacted:

- HQ AFCESA/CESC
  139 Barnes Drive, Suite 1
  Tyndall AFB, FL 32403-5319

Mr James Greene, USAF Pavements Manager	DSN 523-6334	Comm (850) 283-6334
Mr Richard Smith, Pavements Laboratory Manager	DSN 523-6084	Comm (850) 283-6084
FAX	DSN 523-6499	Comm (850) 283-6499

- CEWES-GP-N
  Airfields and Pavements Division
  Geotechnical Laboratory
  U S Army Engineer Waterways Experiment Station
  3909 Halls Ferry Road
  Vicksburg, MS 39180-6199

Dr Albert Bush	Comm (601) 634-3545 or 1-800-522-6937 ext 3545
Mr Don Alexander	Comm (601) 634-2731 or 1-800-522-6937 ext 2731
FAX	Comm (601) 634-3020

C.2. Define Initial Airfield Layout

C.2.1. Make an initial tour of the airfield.

C.2.1.1. Verify dimensions of the airfield and accuracy of existing drawings if available. Existing information on the airfield such as: soil boring data; geological, topographical, and agricultural maps; and aerial photographs would also be helpful if available.

C.2.1.2. Use expedient methods to survey (taping, measuring wheel, or pacing).

C.2.1.3. Update existing plans or make new scaled drawing as required.

C.2.2. Divide the airfield pavement system into features based upon common characteristics which are: the surface type, thickness, and construction history data; available subsurface layer data; use; and traffic type.

C.2.2.1. Surface Types:

- AM-2 Mat
- Gravel / Unsurfaced
- Stabilized Material

Note: A specific feature contains only one surface type.

C.2.2.2. Surface Layer Thickness and Construction History Data. All surface material in a specific feature must share a constant nominal thickness within reason and a common construction history. Construction history is comprised of data regarding the materials used and year of original construction, as well as all subsequent maintenance and repair materials and techniques.

C.2.2.3. Subsurface Layers:

- Types
- Thicknesses
- Strengths

C.2.2.4. Use:

- R = Runway
- O = Overrun
- T = Taxiway
- A = Apron

C.2.2.5. Traffic Type:

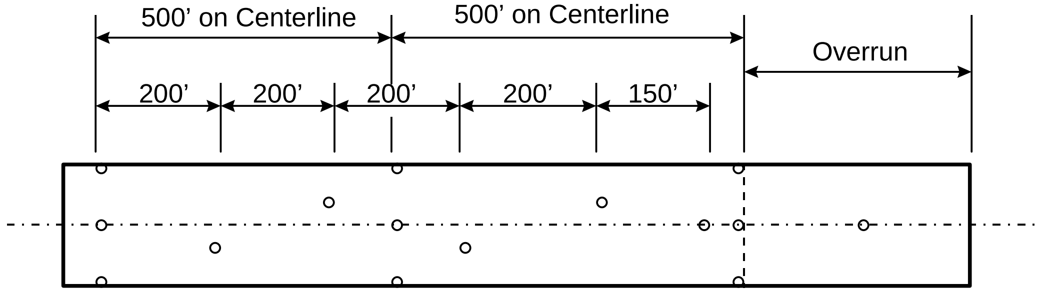
- A = Channelized traffic, full design weight of aircraft (All areas of contingency airfields should be evaluated as A traffic.)

C.2.3. Determine Test Locations. The numbers and locations of soil strength tests and samples will vary with the type of airfield, size of airfield, proposed mission of the airfield, number of features, and time available for conducting the tests. Test locations must be chosen wisely and should accurately cover each feature or aspect of the airfield, yet may need to be minimized due to aircraft operations or time constraints. Soil conditions are extremely variable; therefore, as many tests as time and circumstance will permit should be taken. The strength range and uniformity of the area will control the number of tests required. **In all cases it is advisable to test apparent weak areas first, since the weakest conditions control the pavement evaluation.** In areas of doubtful strength or where evidences of changing layer structure occur, the tests may be closely spaced. On the other hand, in areas where the structure appears to be firm and uniform, tests may be few and widely spaced. After weak areas have been tested, areas of high traffic intensity or loading such as take-off/touch-down zones, runway/taxiway intersections, and taxi lanes on aprons should be tested. Figure C.2 shows recommended test locations for semi-prepared airfields. Conduct as many tests as possible in the time available.

C.3. Collect Field Data to Determine Airfield Structural Properties

C.3.1. Types.

- Identify surface and any underlying base, subbase, and subgrade materials using field identification methods and classify using the United Soil Classification System (USCS). See Appendix A.

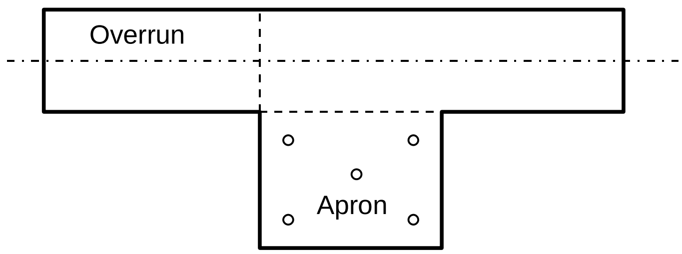


Note: For unimproved airfield, continue this pattern throughout the length. For aggregate surfaced airfields, the pattern may be more widely spaced on the remaining portion of the airfield.

Typical Semi-prepared Airfield

Priority Testing

1. Soft spots
2. Offsets, should be in wheel paths of main gear
3. Centerline
4. Aircraft turnarounds
5. Any area where the aircraft must stop
6. Overrun,one test in center
7. Along edges, at 500 feet intervals



Typical Apron or Turnaround

Figure C.2. DCP Test Locations for Semi-Prepared Airfields

- If field classification methods do not produce clear results or require validation, obtain samples for follow-up laboratory testing
- If materials have been altered or have additives as in the case of dense crushed rock layers or stabilized soil layers, identify them as such

C.3.2. Thicknesses.

- Measure actual layer thicknesses in the wheel paths where possible
- Use Dynamic Cone Penetrometer (DCP) data to determine layer thicknesses
- Be aware of other sources of strata information such as ditches or excavations. This provides useful information on the subbase/subgrade.

C.3.3. Strengths. Shearing resistance is one of the most important properties that a soil possesses. A soil’s shearing resistance under given conditions is related to its ability to withstand a load. The shearing resistance is especially important in its relation to the supporting strength or bearing capacity of a soil used as a base or subgrade beneath airfield pavements. For military pavement applications, the California Bearing Ratio (CBR) value of a soil is used as a measure of soil strength. Laboratory methods of determining CBR values are time consuming and thus impractical for expedient or contingency evaluations. Several methods are available to determine CBR values in the field.

- Dynamic Cone Penetrometer. **The DCP is the preferred method of obtaining CBR field data.** It will penetrate layers having CBR strengths in excess of 100 and will measure soil strengths less than 1. It is a powerful, relatively compact, sturdy device that produces consistent results. Its use will be discussed in detail later in this section.
- Airfield Cone Penetrometer (ACP). The ACP is a probe-type instrument that when pushed down through the soil gives an airfield index (AI) of soil strength. This AI can be correlated to CBR values. This instrument is commonly used by USAF SSTs for expedient evaluations because of its portability and simplicity to operate. Its range is limited to 0 to 18 CBR and it will not penetrate many crusts, thin base course, or gravel materials. Consistency of test results is also difficult due to variability of soil strengths that impact the rate of penetration. Due to this and depth constraints, it is not recommended for C-17 evaluations.
- Electronic Cone Penetrometer (ECP). The contingency soils van operated by HQ AFCESA is equipped with an ECP that is hydraulically pushed through the soil layers to depths of typically five to seven feet. The cone tip pressure is measured and recorded by the on-board computer system and is correlated to CBR values. Soil cohesion measurements are also recorded and used in conjunction with the tip pressure to assist in soil classification. This one-of-a-kind item is also equipped with a core drill capable of coring through flexible and rigid pavement layers as required, is air-transportable by C-130, C-141, C-5, and C-17 aircraft, and provides accurate, consistent data. This van is not available nor appropriate for all contingency evaluations, but its use should be considered when other methods of data collection do not provide clear results.
- Field Small Aperture CBR Test. Standard CBR tests may also be performed on the surface or through core holes in the pavement surface. This use is normally limited to tests on the surface of the base course. These tests may be performed in conjunction with DCP tests to validate the data or as stand alone tests in cases where use of the DCP is not applicable. These tests are described in detail in FM 5-530/AFM 89-3.
- USCS Correlation. This is the quickest, yet least accurate method of determining CBR values. For each soil type, empirical studies have determined a range of CBR values. These values are shown on the Table A.2, Soil Characteristics Chart in Appendix A. These CBR ranges are only estimates and due to the varying soil types and strengths encountered across an airfield, the lowest CBR values in the range should be used, and then with judgment and caution.

C.3.3.1. Measure soil layer thickness and strengths using the DCP.

C.3.3.1.1. Description. The DCP consists of a 16-mm-diameter stainless steel rod with a cone attached to one end which is driven into the soil by means of an 8 kg sliding hammer which is dropped from a height of 575 mm. The angle of the cone is 60 degrees and the diameter of the base of the cone is 20 mm. The rod may either be a scored version or may be smooth requiring the use of an adjacent measuring scale (see

Figure C.3). Units that test both paved and semi-prepared airfields should use 50 inch long rods as shown in Figure C.3, but 36 inch long rods are available and are adequate for semi-prepared airfield evaluations. Disposable cones which mount on an adapter may be used in cases where the cone is difficult to remove from the soil. This disposable cone remains in the soil. Use of disposable cones will increase the number of tests per day that can be accomplished.

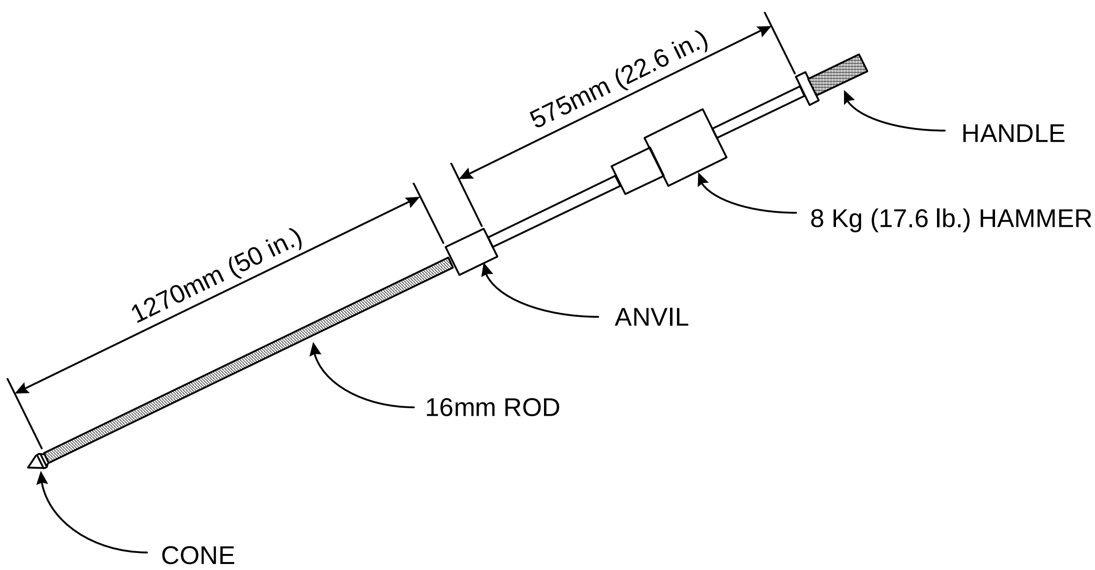


Figure C.3. Dynamic Cone Penetrometer

C.3.3.1.2. Use. Two people are required to operate the DCP. One person, the operator, holds the device by its handle in a vertical position and taps the device using the slide hammer until the base of the cone is flush with the surface of the soil. The second person, or recorder, then measures the distance between the cone and the surface to establish a baseline reading. The operator then raises and releases the hammer. The hammer must be raised to the point of touching the bottom of the handle but not lifting the rod and cone. **The hammer must be allowed to drop freely with its downward movement, not influenced by any hand movement. The operator must be careful not to exert any downward force on the handle after dropping the hammer.** The recorder ensures the device remains in a vertical position, measures the cone penetration, counts the number of hammer drops between measurements, and records the data. The number of blows or hammer drops between measurements is based on the rate of penetration. **The cone should penetrate at least 25 mm or 1 inch between measurements.** Both the operator and recorder should be alert to any sudden increases in cone penetration rates, which indicate weaker soil layers. A measurement should be recorded at that point to indicate the beginning of that layer. After the DCP has been driven to the desired depth, it should be extracted from the soil by bumping the drop hammer against the handle. The hammer must be raised in a vertical direction (rather than in an arching motion) or the rod may be bent or broken where it connects to the anvil. In some soils with large aggregate the DCP may try to penetrate the soil at a slant rather than from a true vertical direction. The operator should not apply force to the handle in an attempt to force vertical penetration. This will potentially break the rod or connections. **Instead, the test should be stopped if the handle deviates from plumb more than 6 inches and a new test should be attempted in close proximity of the failed test.**

- Maintenance of Equipment. The DCP should be kept clean and all soil should be removed before each test. Graphite, spray lubricant, or oil should be applied to the hammer slide before use each day. All joints should be constantly monitored and kept tight. Loctite may be used. The lower rod should be kept clean and lubricated when clayey soils are tested.
- Recording Data. A suggested format for DCP data collection is shown in Figure C.4. The number of blows and penetration depths must be recorded during the test. Depending on the scale used, the depth of penetration readings is measured and recorded to the nearest 5 mm or 0.2 inches.

DCP DATA SHEET							
BASE:		**FEATURE:**			**DATE:**		
TEST#:		**TEST LOCATION:**					
No of Blows (1)	**Accum. Penetration mm (2)**	**Penetration p/Blow Set mm (3)**	**Penetration per Blow mm (4)**	**Hammer Blow Factor (5)**	**DCP Index (6)**	**CBR % (7)**	**Depth in. (8)**

(1) No. of hammer blows between test readings

(2) Accumulative cone penetration after each set of hammer blows

(3) Difference in accumulative penetration (2) at start and end of each hammer blow set

(4) (3) divided by (1)

(5) Enter 1 for 17.6 lb hammer, 2 for 10.1 lb hammer

(6) (4) x (5)

(7) From CBR versus DCP correlation (table C.2 or C.3)

(8) Previous entry in (2) divided by 25.4 rounded off to 0.2 in.

Figure C.4. DCP Data Sheet

C.3.3.1.3. Surface Layer Strengths. Lack of confinement at the top of the surface layer affects the DCP measurements. The penetration depth required to measure the surface layer strength accurately is related to the gradation and plasticity characteristics of the materials. The DCP can measure strengths of thin surface layers of fine-grained plastic materials but requires thicker surface layers for the non-plastic coarse-grained materials. The penetration depth required for measuring actual strength of the surface layer with the DCP is shown in Table C.1 for the various soil types.

Table C.1. Depth Required to Measure Surface Layer Strength (No Overburden)

Soil Type	Average Penetration Depth (inches)
CH	1
CL	3
SC	4
SW-SM	4
SM	5
GP	5
SP	11

Note: The shearing action of the C-17 while braking during landing operations will create loose till on dry unstabilized soil surfaced runways in arid or semi-arid regions. The number of allowable passes may be significantly lower than those predicted using standard evaluation procedures. The DCP data collected at the top of the surface layer in the unconfined material, if treated as a separate layer in calculating allowable loads or passes, may provide a good indication of the surface capability to withstand the additional loads and stresses expected during landing operations.

C.3.3.1.4. Depth of Tests. The C-17 aircraft may affect the soil to depths of 36 inches or more; therefore, it is recommended that DCP tests be conducted to the full depth of the rod. **If a test must be discontinued short of full rod depth, a new test should be accomplished nearby.**

C.3.3.1.5. Correlation of DCP Readings to CBR.

- If using the U.S.Army Corps of Engineers Waterways Experiment Station developed DCP software program, the CBRs are computed for the user based upon the number of blows and penetration depths inputted. The DCP program will also display a graph of the CBR values in relation to the depths measured and is useful in determining layer thicknesses. See Figure C.5.
- If using manual field plotting methods, the CBRs may be obtained from Tables C.2 and C.3 or Figure C.6. Table C.2 correlations should be used for all soil groups other than CH and CL with a CBR below 10. Table C.3 correlations should be used for all CH soils and for CL soils with a CBR less than 10. When using these tables, CBRs should be rounded to the nearest whole number. Figure C.6 shows a plot of all correlations.
- The DCP data may also be easily plotted on graph paper and the resulting soil layer thicknesses and corresponding CBRs may be determined. Figure C.7 is an example of this method.

DCP TEST DATA

File Name: DCP

Project: *Example DCP Data Plot*

Location:

Date:

Soil Type(s): SP, Poorly Graded Sand

Hammer
- ○ 10.1 lbs
- ◉ 17.6 lbs
- ○ Both hammers used

Soil Type
- ○ CH
- ○ CL
- ◉ All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	0	1
1	25	1
2	65	1
2	90	1
2	115	1
3	145	1
3	170	1
3	195	1
3	220	1
4	250	1
4	280	1
4	305	1
4	335	1
4	370	1
4	400	1
3	430	1
3	465	1
3	500	1
2	530	1
2	560	1
2	590	1
2	620	1
3	660	1
2	690	1
2	725	1
2	765	1
2	805	1
2	850	1
1	875	1
1	905	1
1	935	1
1	970	1
1	1005	1
1	1035	1
1	1075	1
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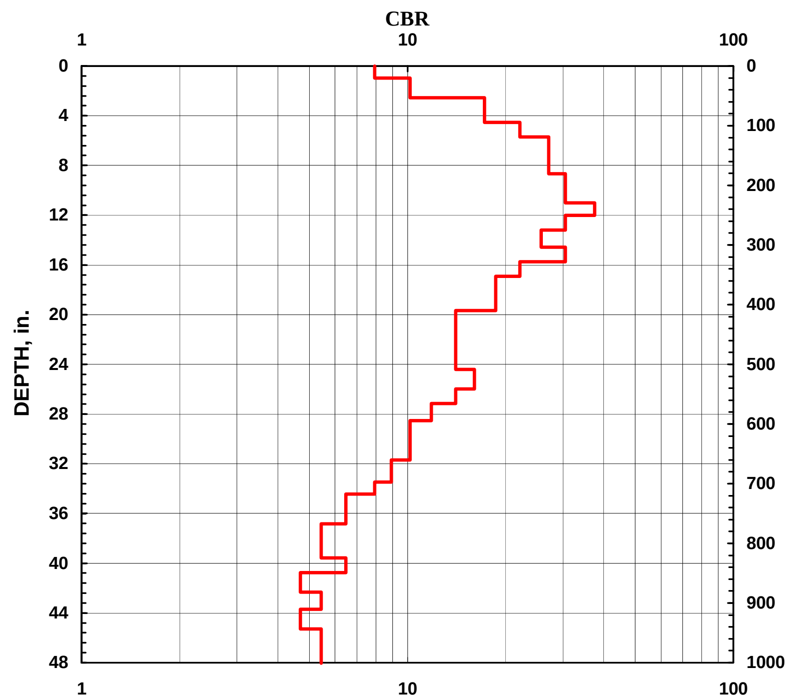
1	1220	1
		1
		1
		1
		1



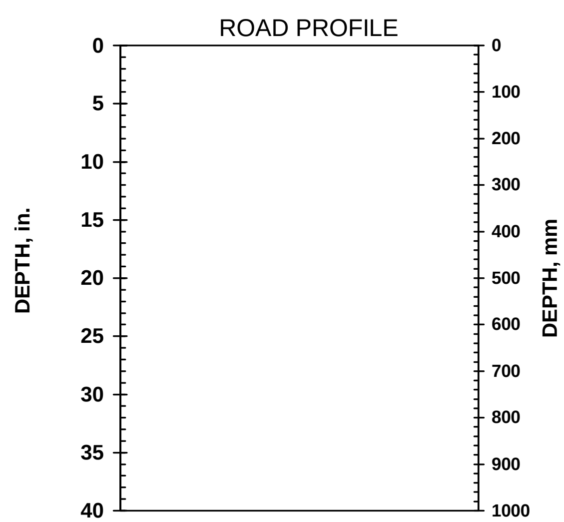


Figure C.5. Software Plot of DCP Data

Table C.2. Tabulated Correlation of DCP Index vs CBR

DCP Index mm/blow	in/Blow	CBR	DCP Index mm/blow	in/Blow	CBR	DCP Index mm/blow	in/Blow	CBR
<3	0.10	100	12		18	56-57	2.20	3.2
	0.11	92		0.50	17	58		3.1
	0.12	84	13		16	59-60		3.0
3		80	14	0.55	15	61-62	2.40	2.9
	0.13	76	15	0.60	14	63-64	2.50	2.8
	0.14	70	16	0.65	13	65-66	2.60	2.7
	0.15	65	17	0.70	12	67-68		2.6
	0.16	61	18-19		11	69-71	2.80	2.5
4		60	20-21	0.80	10	72-74		2.4
	0.17	57	22-23	0.90	9	75-77	3.00	2.3
	0.18	53	24-26	1.0	8	78-80		2.2
5	0.19	50	27-29		7	81-83		2.1
	0.20	47	30-34	1.20	6	84-87	3.40	2
	0.21	45	35-38	1.40	5	88-89	3.50	1.9
	0.22	43	39		4.8	92-96		1.8
	0.23	41	440		4.7	97-101	4.00	1.7
6		40	41	1.60	4.6	102-107		1.6
	0.24	39	42		4.4	108-114		1.5
	0.25	37	43		4.3	115-121		1.4
7	0.26	35	44		4.2	122-130	5.00	1.3
	0.27	34	45		4.1	131-140		1.2
	0.28	32	46	1.80	4	141-152		1.1
	0.29	31	47		3.9	153-166	6.00	1
8	0.30	30	48		3.8	166-183	7.00	0.9
9	0.35	25	49-50		3.7	184-205	8.00	0.8
	0.40	22	51	2.0	3.6	206-233	9.00	0.7
10-11		20	52		3.5	234-271	10.00	0.6
	0.45	19	53-54		3.4	272-324		0.5
			55		3.3	>324		<0.5

Table C.3. Tabulated Correlation of DCP Index vs CBR - CH and CL Type Soils

CH						CL					
DCP Index mm/Blow	in/Blow	CBR	DCP Index mm/Blow	in/Blow	CBR	DCP Index mm/Blow	in/Blow	CBR	DCP Index mm/Blow	in/Blow	CBR
10	0.4	35	115	4.5	3.0	19	0.7	9.6	40	1.6	2.2
15	0.6	23	120	4.7	2.9	20	0.8	8.6	41	1.6	2.1
20	0.8	17	125	4.9	2.8	21	0.8	7.8	42	1.7	2.0
25	1.0	14	130	5.1	2.7	22	0.9	7.1	43	1.7	1.9
30	1.2	12	135	5.3	2.6	23	0.9	6.5	44	1.7	1.8
35	1.4	10	140	5.5	2.5	24	0.9	6.0	45	1.8	1.7
40	1.6	8.7	145	5.7	2.4	25	1.0	5.5	46	1.8	1.6
45	1.8	7.7	150	5.9	2.3	26	1.0	5.1	47	1.9	1.6
50	2.0	7.0	155	6.1	2.3	27	1.1	4.7	48	1.9	1.5
55	2.2	5.3	160	6.3	2.2	28	1.1	4.4	49	1.9	1.4
60	2.4	5.8	165	6.5	2.1	29	1.1	4.1	50	2.0	1.4
65	2.6	5.4	170	6.7	2.0	30	1.2	3.8	51	2.0	1.3
70	2.8	5.0	>175	>6.9	<2.0	31	1.2	3.6	52	2.0	1.3
75	3.0	4.6				32	1.3	3.4	53	2.1	1.2
80	3.1	4.3				33	1.3	3.2	54	2.1	1.2
85	3.3	4.1				34	1.4	3.0	55	2.2	1.1
90	3.5	3.9				35	1.4	2.8	56	2.2	1.1
95	3.7	3.7				36	1.4	2.7	57	2.2	1.1
100	3.9	3.5				37	1.5	2.5	58	2.3	1.0
105	4.1	3.3				38	1.5	2.4	>59	>2.3	<1.0
110	4.3	3.2				39	1.5	2.3			

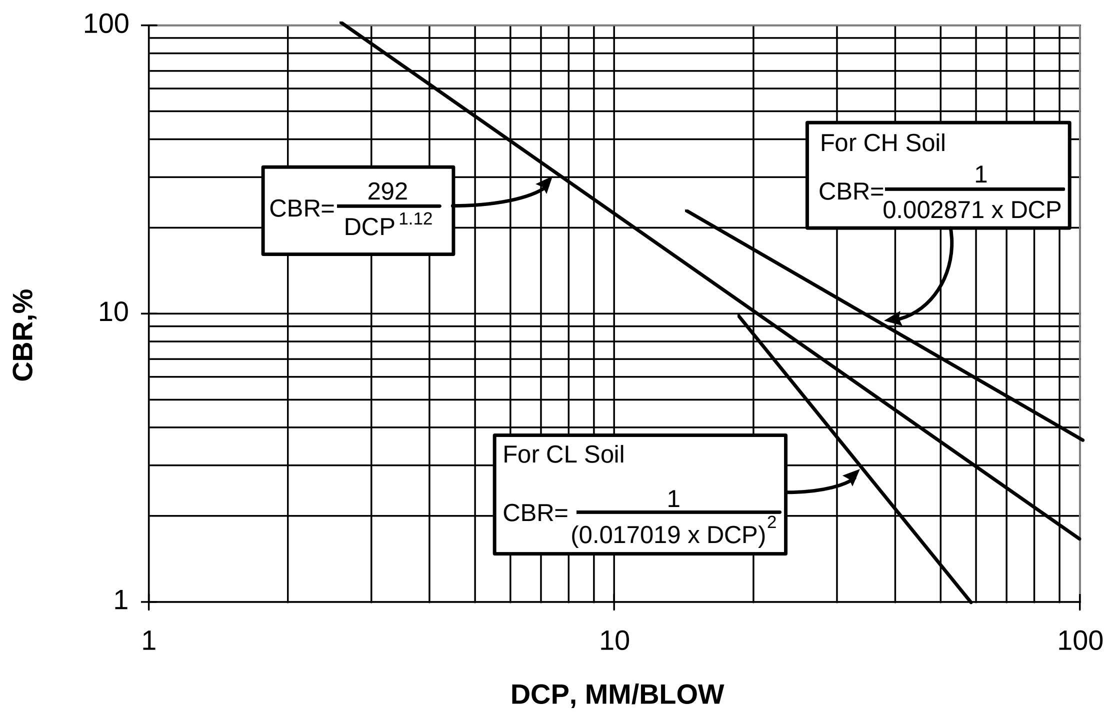


Figure C.6. Plotted Correlation of DCP Index vs CBR

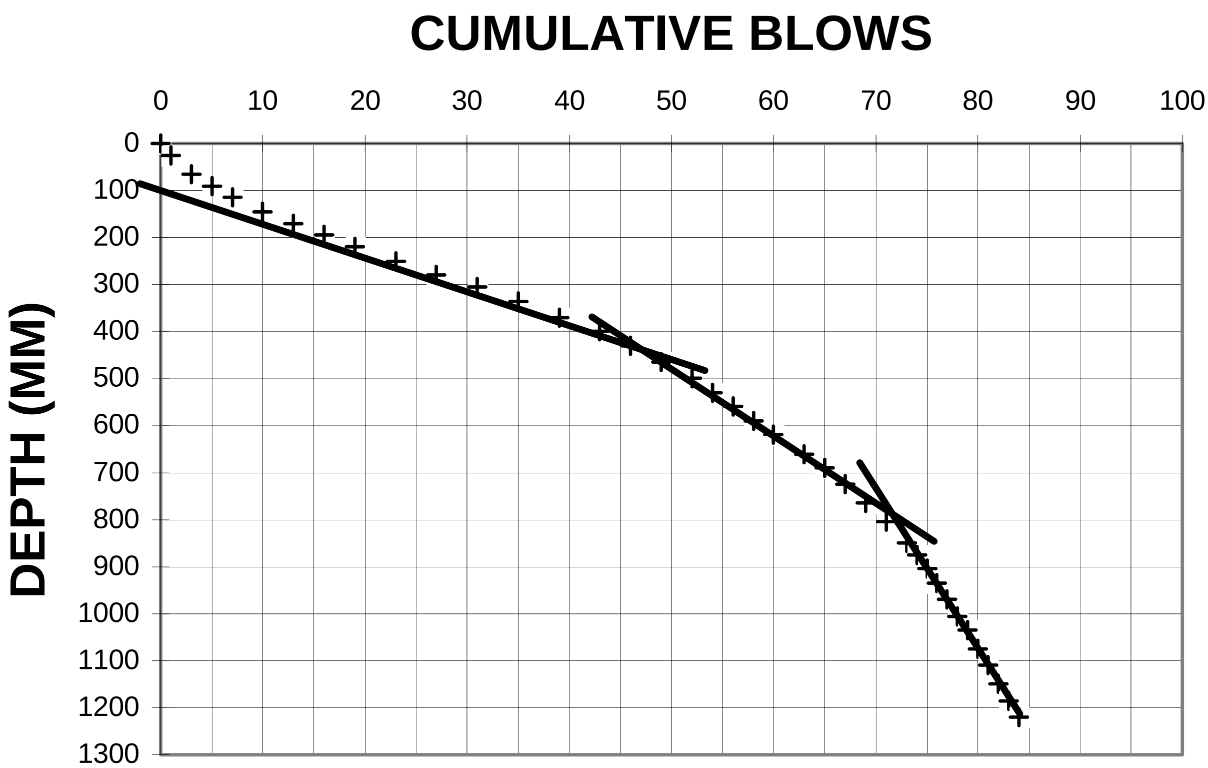


Figure C.7. Manual Plot of DCP Data

- Plot. Annotate the total number of blows needed in a particular DCP test being plotted along one axis of the graph. Annotate the depth of penetration along the other axis. Then plot the points as recorded on the DCP Data Sheet.
- Layers. Draw straight lines tangent to or through the points that are reasonably straight. These lines indicate the soil layers with the intersecting points indicating the layer breaks. Disregard the top few measurements of the test in this process. In our example, the first layer break is located at 420mm or 16" so the thickness of layer 1 is 16". The second layer break is at 800mm or 31" so the thickness of layer 2 is 15". This is continued throughout the depth of the test.
- DCP Index. The layer DCP index is established by dividing the depth of penetration by the number of blows. In our example, the first straight line intersected the depth axis at 70mm and the layer break point at 420mm so the depth for determination of DCP index is 350mm. It took 46 blows to reach the first layer break. Dividing 350 by 46 results in a DCP index of 7.6 for this layer. DCP indexes for the remaining layers are determined the same way, by using the number of blows and depth measurements between layer breaks. Our DCP index for layer 2 is 14.6 and the DCP index for layer 3 is 35.

– CBRs. Tables C.2 and C.3 are then used to determine the CBRs for each layer. In our example, the soils tested were classified as SP or poorly graded sand so we used Table C.2. Our depth measurements were in milimeters so we enter the table in the DCP Index mm/blow columns as appropriate to find the corresponding CBRs. A CBR of 32 resulted for layer 1, CBR 14 for layer 2, and CBR 5 for layer 3.

C.3.3.1.6. Special Considerations.

- DCP tests in highly plastic clays are generally accurate for depths to approximately 12 inches. At deeper depths, clay sticking to the lower rod may indicate higher CBR values than actually exist. Oiling the rod will help, without significantly impacting the test results. It may be wise to auger out the test hole after each 12 inch depth encountered to eliminate the clay related friction problems and allow more accurate measurements.
- Many sands occur in a loose state. Such sands when relatively dry will show low DCP index values for the top few inches and then may show increasing strength with depth. The confining action of aircraft tires will increase the strength of sand. All sands and gravels in a "quick" condition (water percolating through them) must be avoided. Evaluation of moist sands should be based upon DCP test data.
- If the cone does not penetrate significantly (approximately one-half inch) after 10 blows, the test should be stopped. **If the material encountered is a stabilized material or high strength aggregate base course which does not produce accurate results when penetrated with the DCP, it should be cored or augered through its depth and the DCP operation resumed beneath it.** An appropriate CBR should be assigned to this layer. If large aggregate is encountered, the test should be stopped and a new test should be performed within a few feet of the first location. **The DCP is generally not suitable for soils having significant amounts of aggregate larger than 2 inches.** CBR values for unpenetrable materials must be carefully selected based upon their service behavior. Suggested CBR values for such materials are:

– Graded Crushed Aggregate	100
– Macadam	100
– Bituminous Binder	100
– Limerock	80
– Stabilized Aggregate	80
– Soil Cement	80
– Sand/Shell or Shell	80
– Sand Asphalt	80

C.3.3.2. Other Strength Factors

C.3.3.2.1. Surface and Subsurface Drainage.

- Locate depth of water table

- Look at contours in area, signs of surface drainage problems, and wet or swampy areas
- Coarse-grained soils have better internal drainage
- Moisture content plays significant role in bearing capacity
- Note the size and depth of any storm drain culverts under the pavement

C.3.3.2.2. Cut/fill areas indicate possible feature changes based on changing subsurface layers.

C.3.3.2.3. Frost Areas.

- Subgrade strengths are reduced significantly during thaw periods if the potential exists for structural failure due to frost. Detrimental frost action will occur if the subgrade contains frost-susceptible materials, the temperature remains below freezing for a considerable amount of time, and an ample supply of ground water is available. If all three conditions exist and frost damage is apparent, Frost Area Soil Support Indexes (FASSIs) are used in lieu of CBRs.
  - F1 and S1 Soils = 9.0 FASSI
  - F2 and S2 Soils = 6.5 FASSI
  - F3 and F4 Soils = 3.5 FASSI
- Clays , silts, and some gravelly and sandy soils with high percentages of fines are frost susceptible. See Table C.4, Frost Design Soil Classifications.
- Areas of frost heave when no longer frozen may have large subsurface voids and will not support projected loads. These areas must be properly recompacted.

C.3.3.2.4. Wet Climate.

- Soil layer strengths in areas subject to heavy seasonal rains or flooding may react similarly to those in frost susceptible areas. This is particularly true in the case of fine-grained materials containing clays and/or silts where there is no adequate surface seal, or positive drainage away.
- Moisture conditions at the time of testing should be documented (Is it dry, damp, or wet?) and anticipated conditions for the projected usage period must be considered in determining the validity of test data for intended aircraft operations.

C.4. Obtain Aircraft Operational Requirements

C.4.1. Obtain aircraft operational requirements from the Site Operations Officer, local Command Section, or the tasking OPR.

C.4.2. Data Required for C-17 Aircraft

Table C.4. Frost Group Designations for Soil Classification Required for Frost Design

Frost Group	Type of Soil	% by Weight < 0.02 mm	Typical Soil Types under the USCS
NFS	(a.) Gravels (e > 0.25)	0-3	GW, GP
	Crushed Stone	0-3	GW, GP
	Crushed Rock	0-3	GW, GP
	(b.) Sands (e < 0.30)	0-3	SW, SP
	(c.) Sands (e > 0.30)	3-10	SP
S1	(a.) Gravels (e < 0.25)	0-3	GW, GP
	Crushed Stone	0-3	GW, GP
	Crushed Rock	0-3	GW, GP
	(b.) Gravelly soils	3-6	GW, GP, GW-GM, GP-GM, GW-GC, and GP-GC
S2	Sandy soils (e < 0.30)	3-6	SW, SP, SW-SM, SP-SM, SW-SC, and SP-SC
F1	Gravelly soils	6-10	GW-GM, GP-GM, GW-GC, and GP-GC
F2	(a.) Gravelly soils	10-20	GM, GC, GM-GC
	(b.) Sands	6-15	SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, and SM-SC
F3	(a.) Gravelly soils	>20	GM, GC, GM-GC
	(b.) Sands (not very fine silty sands)	>15	SM, SC, SM-SC
	(c.) Clays (PI > 12)	-	CL, CH, ML-CL
F4	(a.) Silts	-	ML, MH, ML-CL
	(b.) Very fine sands	>15	SM, SC, SM-SC
	(c.) Clays (PI < 12)	-	CL, ML-CL
	(d.) Varved clays or fine-grained banded sediments	-	CL or CH layered with ML, MH, SM, SC, SM-SC, or ML-CL
NOTE: e = void ratio. NFS indicates non frost susceptible material			

C.4.2.1. Loads. Gross weights of anticipated mission aircraft, including cargo and fuel.

C.4.2.2. Traffic Volume. The expected number of passes anticipated for each aircraft type. For a runway, passes are determined by the number of aircraft movements across an imaginary traverse line placed within 500 feet of the end of the runway. Simply stated, it is one aircraft movement over a given area. For taxiways and aprons, passes are determined by the number of aircraft cycles across a line on the primary taxiway that connects the runway and parking areas. For contingency evaluations, if the operational data received specifies the number of required missions for a given aircraft, this number should be doubled to determine the number of passes.

C.4.2.3. Aircraft ground operations such as turn-arounds and taxi routes determine designations of feature types and resulting gross loads. Additional aircraft movements on the runway, i.e. back-taxiing in the case of an airfield with no parallel taxiway and apron system, will also increase the number of passes per each planned mission.

C.5. Conduct Surface Condition Visual Assessment. Visual surveys of the airfield surface can provide information on apparent structural integrity, operational condition, and projected performance. A cursory inspection of the features should be performed and the distress types, quantities, and severity levels as described in Appendix B should be identified. The features should then be assigned overall condition ratings.

C.6. Refine Airfield Layout/Compile Summary of Physical Property Data (PPD). Update the airfield layout based upon aircraft operational requirements, surface condition assessment, and results of field test data. Each feature should now be distinguishable by the characteristics of surface type, thickness, and condition; subsurface layer types, thicknesses, and strengths; construction history; use; and traffic type. One method to consolidate the cross section or pavement system profile data obtained from field tests and construction history into specific features is to:

C.6.1. Arrange pavement and soil profile data in relation to the actual test locations on the airfield. This will show the range of values and relationship of any given test location data to that at adjacent test locations.

C.6.2. Group those containing common characteristics into features.

C.6.3. Establish the representative profile for each feature. In most cases, the CBR values selected for a feature should be a low average of those collected from all the test locations within the feature, but this is not always true. Conditions are seldom uniform and sound engineering judgment should be used.

C.6.4. Compile the characteristics for each feature into the Summary of PPD. This information will be used to determine the allowable gross loads and/or allowable passes for the airfield (see Figure C.8).

C.7. Determine Allowable Gross Loads (AGLs)/ Allowable Passes

C.7.1. Semi-Prepared Airfields. Semi-prepared airfields may be evaluated for various aircraft using the US Army Waterways Experiment Station developed software program UNSEVA, Computer Aided Evaluation of Expedient Airfields or manually using Figure C.9, CBR Nomograph and Semi-Prepared Surface Evaluation Curve, Figure C.10.

C.7.1.1. If using the UNSEVA program:

C.7.1.1.1. Double-click on the icon to bring up the Expedient Airfields screen. Inputs from this screen are somewhat self-explanatory.

C.7.1.1.2. Choose the aircraft type from the list.

SUMMARY OF PHYSICAL PROPERTY DATA: SEMI-PREPARED AIRFIELDS													
FACILITY					SURFACE			SUBBASE			SUBGRADE		
FEAT	IDENT	LGTH (ft)	WDTH (ft)	COND	THICK (in)	DESCRP	CBR	THICK (in)	DESCRP	CBR	THICK (in)	DESCRP	CBR

Figure C.8. Summary of Physical Property Data Sheet

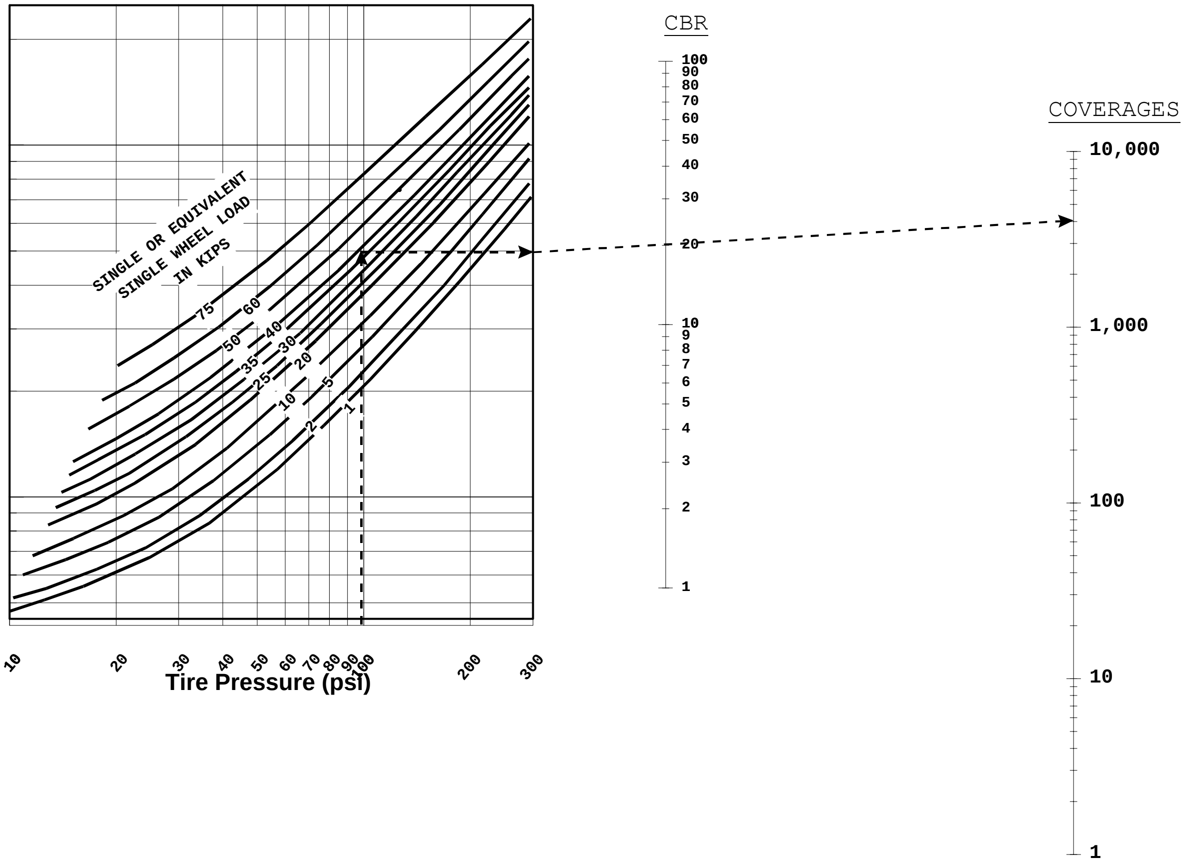


Figure C.9. CBR Required for Operation of Aircraft on Semi-Prepared Airfields

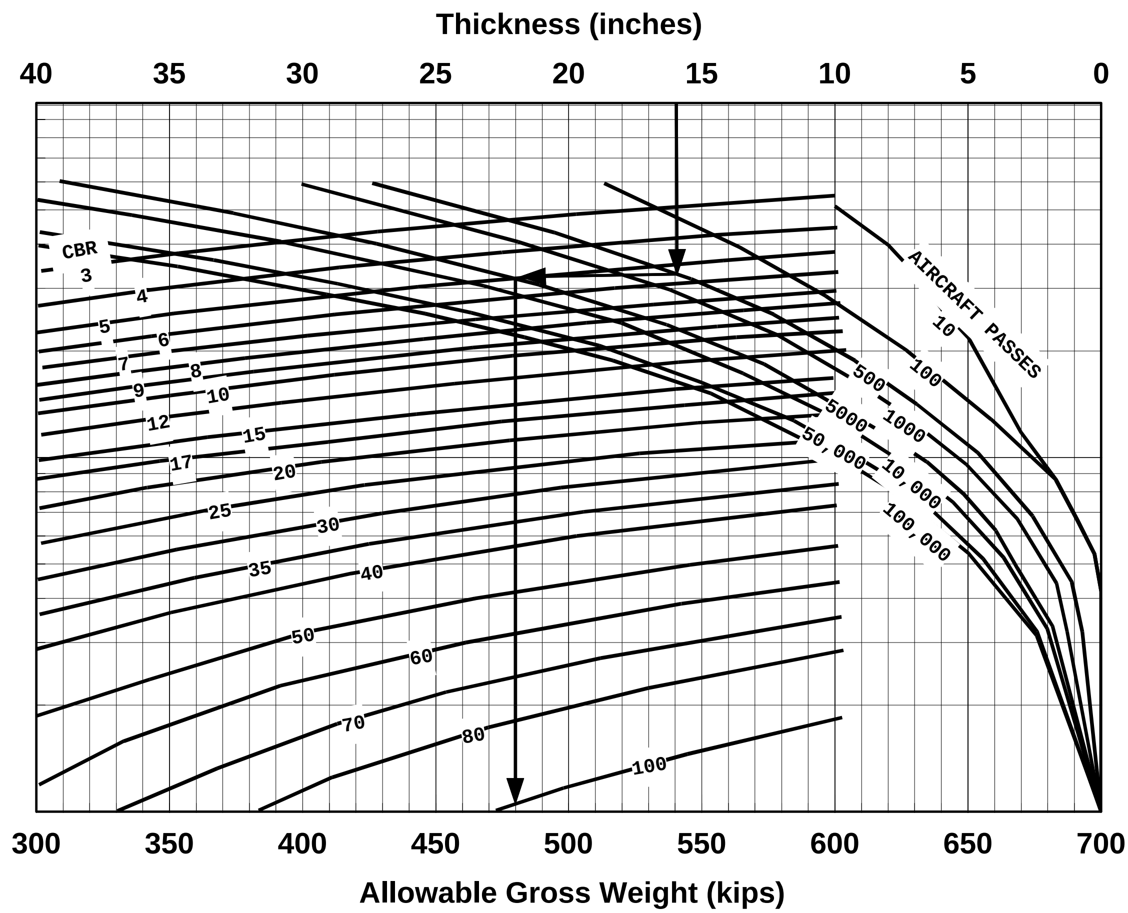


Figure C.10. Semi-Prepared Surface Evaluation Curve, C-17

C.7.1.1.3. Choose the type of evaluation, for allowable passes or loads.

- If evaluating for loads, enter the number of design passes.
- If evaluating for passes, the design load is automatically adjusted when the type aircraft is selected, but this can be altered. For example, if the C-17 aircraft is selected, the design load of 580,000 lbs. is shown. This is the maximum design load of the aircraft. If you wanted to determine the allowable passes for a C-17 weighing 447,000 lbs., simply change the design load entry.

C.7.1.1.4. Enter correct base course CBR and thickness.

C.7.1.1.5. Enter correct subgrade CBR and select the appropriate subgrade frost code.

C.7.1.1.6. Under usual circumstances, do not alter the tire pressure data. This is automatically adjusted when the type aircraft is selected.

C.7.1.1.7. The allowable passes or loads may then be read in the results fields for the surface and subgrade layers. The lower of the two numbers would establish the controlling layer for the evaluation.

Note: This program limits CBR inputs to two layers. Careful analysis of the DCP data is required to ensure that the layer data entered in the program represents that which was determined in the field. For semi-prepared surface evaluations, primary concern is given to the DCP data taken from the top 24 inches of soil.

C.7.1.2. Two steps are required to manually evaluate semi-prepared airfields: first, evaluate for the strength of the surface layer; and second, evaluate for the thickness of the surface layer and the strengths and thicknesses of underlying layers.

C.7.1.2.1. Evaluate Surface Layer Strength. A nomograph (Figure C.9) has been developed to determine the strength of soil required to support a given loading condition based upon the tire pressure, load, soil strength, and traffic. The tire pressure is the contact tire pressure, the soil strength is the CBR of the surface layer, the traffic is measured in coverages, and the load is the single-wheel load or the equivalent single-wheel load (ESWL). To use this nomograph:

- Enter the chart with the expected contact tire pressure of the aircraft being evaluated. See Table C.5 for contact tire pressure data for the C-17 at various mission gross weights.
- Move vertically to the appropriate ESWL curve. See Table C.5 for ESWLs for various gross weights.
- Move horizontally to the right edge of the chart.
- At that point, project a straight line through the measured CBR value of the surface layer to read the number of coverages.
- Convert coverages to passes using Table C.5.

Table C.5. ESWLs and Tire Pressures for C-17 Aircraft

Aircraft	Gross Weight (kips)	Surface ESWL (kips)	Contact Tire Pressure (psi)	Pass/Coverage Ratio A Traffic
C-17	580	55.2	142	1.37
	500	47.5	122	
	450	42.9	110	
	425	40.5	104	
	400	38.1	98	
	350	33.3	84	

Note: A coverage differs from a pass. A pass simply represents an aircraft movement across a given point on the airfield; whereas, a coverage takes into account the fact that aircraft wander somewhat and the wheels do not follow the same identical path on each pass. To determine the number of passes multiply the number of coverages by the pass/coverage ratio for the aircraft and traffic area being evaluated.

C.7.1.2.2. Evaluate Surface Layer Thickness.

- Select Figure C.10, Semi-Prepared Surface Evaluation Curve, C-17.

- Using the layer data from the PPD, enter the top of the chart with the thickness of the aggregate surface layer. Draw a vertical line (Line 1) downward through the aircraft pass levels. Also enter the bottom of the chart at the desired gross weight, draw a line vertically to the curve depicting the CBR of the layer immediately beneath the surface layer, then horizontally to intersect Line 1. This point of intersection defines the allowable number of passes. If this number is equal to or exceeds the number of passes computed during the evaluation of the surface layer strength then the thickness of the surface layer is adequate.

Note: This step evaluates the layer immediately beneath the surface layer as well as the thickness of the surface layer.

C.7.1.2.3. Evaluate remaining subsurface layers. Repeat this procedure for each soil layer. Enter the top of the chart with the thickness above the layer being evaluated and use the CBR of the layer being evaluated. The layer that produces the lowest allowable number of passes is the controlling layer for the evaluation.

Example: Determine the allowable number of passes for a 400,000 lb. C-17 aircraft on the following soil cross section in an A traffic area:

8” Aggregate Surface Course, CBR: 20
8” Subbase Course, CBR: 15
Subgrade, CBR: 5

Solution:

- Step 1, Evaluate Surface Course Strength:
  - Enter the nomograph chart at 98 PSI, the expected contact tire pressure for the C-17.
  - Move vertically to the 38.1 ESWL curve and then horizontally to the right edge of the chart.
  - Draw a straight line from this point through the CBR line at 20 and read 4,000 coverages.
  - Multiply 4,000 coverages by 1.37 to determine the allowable number of passes, which is 5,480.
- Step 2, Evaluate Surface Layer Thickness:
  - Select the Semi-Prepared Surface Evaluation Curve for the C-17.
  - Enter the top of the chart at 8 inches drawing a vertical line (Line 1) downward through the aircraft pass curves.
  - Enter the bottom of the chart at 400,000 lbs and draw a vertical line up to the 15 CBR curve, then horizontally to intersect with Line 1.
  - The point of intersection indicates an allowable pass number of approximately 2,500.
- Step 3, Evaluate the Subgrade:
  - Enter the top of the chart at 16 inches drawing a vertical line (Line 1) downward through the aircraft passes.

  - Enter the bottom of the chart at 400,000 lbs and draw a vertical line up to the 5 CBR curve, then horizontally to intersect with Line 1.
  - The point of intersection indicate an allowable pass number of approximately 1,000.
- In this example, the subgrade layer results in the lowest allowable number of passes. The maximum allowable number of C-17 passes at a gross weight of 400,000 lbs is 1,000.

C.7.1.2.4. A Subgrade Strength Chart, Figure C.11, is also useful in that it provides subgrade strength requirements for mat-surfaced airfields. Enter the left side of the chart with the measured CBR. Follow horizontally to the curve indicating the surface condition (unsurfaced, light-duty mat, or medium-duty mat) and aircraft gross weight. Then read downward to determine the allowable aircraft cycles. One cycle is equal to one take-off and one landing. AM-2 is considered medium-duty mat.

C.7.1.2.5. The Subgrade Strength Chart is limited to one CBR input, so care must be given to ensure that the chosen CBR value is truly representative. This is not difficult for a soil that exhibits a uniform CBR and soil characteristics to a depth of 24 inches. If the soil strength varies through this depth, the evaluation must be made using the critical CBR of the soil.

- Soil Strength Increases with Depth: Use the average CBR for the top 12 inches as the critical CBR.
- Very Soft Layer over Hard Layer:
  - If soft layer is 4 inches thick or less, discard the soft layer CBR values. Use the average CBR for the 12 inch layer under the soft layer as the critical CBR.
  - If the soft layer is more than 4 inches thick, the soft layer should be reduced by grading to less than 4 inches. If this can not be done use the average CBR for the top 12 inches as the critical CBR.
- Hard Layer over Soft Layer:
  - If the hard layer is less than 12 inches thick, use the average CBR of the 12 inch layer under the hard layer as the critical CBR.
  - If the hard layer is more than 12 inches thick, use the average CBR of the data taken between the 12 and 24 inch depths as the critical CBR.
- Soil Strength Decreases with Depth: Determine the average CBRs for various 12 inch layers such as 6 to 18 inches, 8 to 20 inches, 10 to 22 inches, and 12 to 24 inches. Use the lowest average CBR of these layers as the critical CBR.

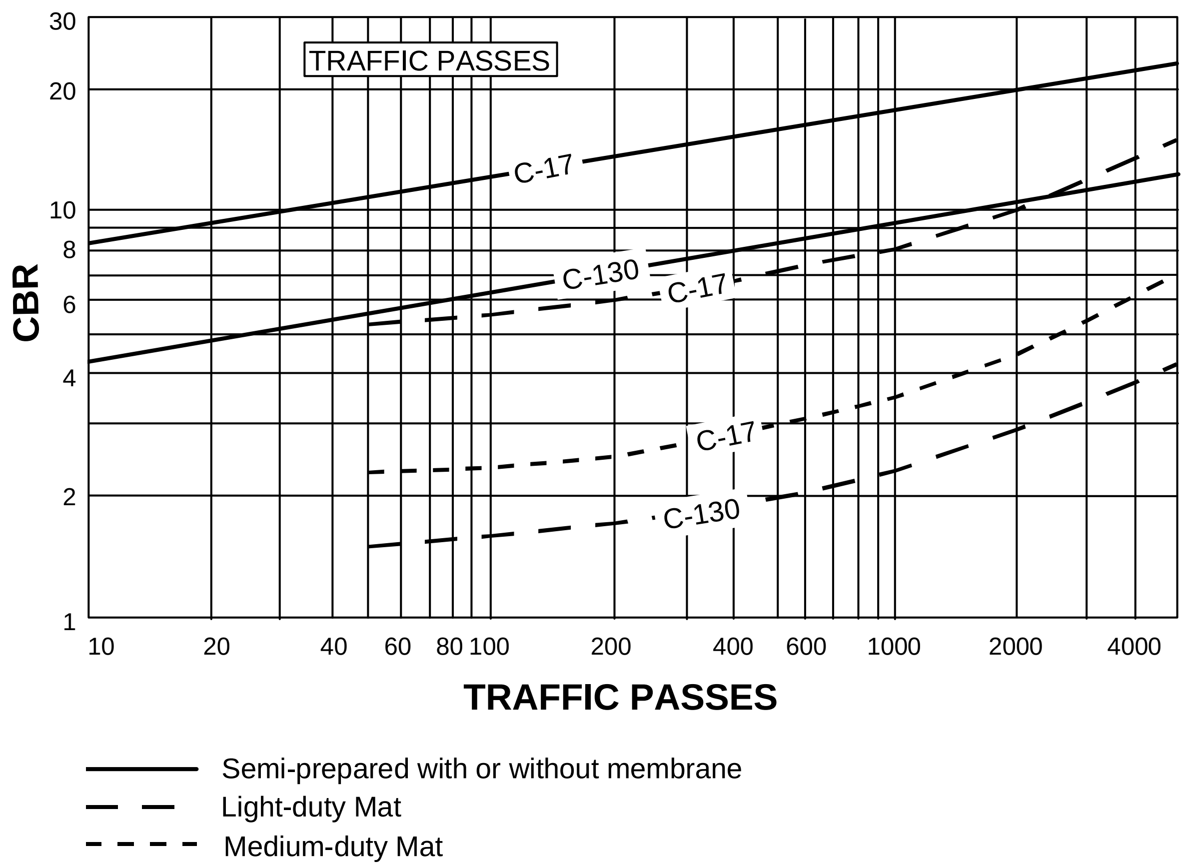


Figure C.11. Subgrade Strength Requirements for C-17

C.7.2. AM-2 Mat Surfaced Airfields. Refer to the curves and procedures in Chapter 4, Structural Design Criteria to determine suitability of AM-2 mat surfaced airfields.

C.8. Determine Aircraft Classification Number/Pavement Classification Number (ACN/PCN). This system is included for mission planning purposes.

C.8.1. In 1983 the International Civil Aviation Organization (ICAO) developed and adopted a standardized method of reporting pavement strength. This procedure is known as the Aircraft Classification Number / Pavement Classification Number (ACN/PCN) method. The ACN is a number that expresses the effect an aircraft will have on a pavement system. The PCN is a number that expresses the capability of a pavement to support aircraft. Once AGLs are computed for each feature of a given airfield, they should be converted to PCNs. PCNs for a given feature will vary depending on which aircraft and number of passes they are based upon. All reports generated by HQ AFCESA for surfaced airfields base the PCNs on the AGLs for the C-141 aircraft at 50,000 passes. This standard will be changed to the C-17 aircraft. This facilitates pavement strength comparisons of bases throughout the Air Force.

PCNs for flexible and rigid pavement systems will be based upon 50,000 passes of the C-17 at a maximum weight of 586,000, and **PCNs for semi-prepared airfields will be based upon 1,000 passes of the C-17 at a maximum weight of 447,000 pounds**.

C.8.2. In the ACN/PCN method; the PCN, pavement type, subgrade strength category, tire pressure category, and evaluation method are reported together in a code system. This code system is presented in Table C.6. Although ICAO does not currently include semi-prepared airfields in the ACN/PCN reporting method, the ACN/PCN method may be a useful tool in mission planning. The symbol "S" should be used to identify the pavement type in the reported PCN code. The subgrade strength codes should be the same as those used for flexible pavements based upon CBR values.

Table C.6. ACN/PCN Code

PCN	Pavement Type	Subgrade Strength	Tire Pressure	Method of PCN Determination
Numerical Value	R=Rigid	A=High	W=High	T=Technical Evaluation
		B=Medium	X=Medium	
	F=Flexible	C=Low	Y=Low	U=Using Aircraft
	S=Semi-Prepared	D=Ultralow	Z=Ultralow	

Subgrade Strength Code	Flexible Pavement (CBR)	Rigid Pavement (k)	Tire Pressure Code	Pressure (psi)
A	Over 13	Over 400	W	No Limit
B	8 - 13	201 - 400	X	146 - 217
C	4 - 8	100 - 200	Y	74 - 145
D	< 4	< 100	Z	0 - 73

Example: If the reported PCN for a feature is 50/S/A/X/T, “50” indicates the PCN number, “S” indicates that it is an semi-prepared airfield, “A” indicates a high subgrade strength, “X” indicates that medium tire pressures are allowed, and “T” indicates that a technical evaluation was performed to determine the PCN. Each part of the code is important. The number “50” cannot be used properly without the letters that follow.

C.8.3. Once an AGL has been determined for an airfield feature, this should be converted to a PCN using the Semi-Prepared ACN/PCN Curves, Figure C.12. For example, during the evaluation of an semi-prepared airfield with a subgrade strength of 12 CBR, it was determined that in order to complete 1,000 passes of the C-17 on the airfield its AGL must be limited to 425,000 pounds. To determine the airfield PCN, enter the bottom of the chart in Figure C.12 at 425 and extend the line vertically until it intersects the "B" subgrade strength curve. At this point extend the line horizontally to determine the PCN of "50". This would be reported as "50/S/B/X/T".

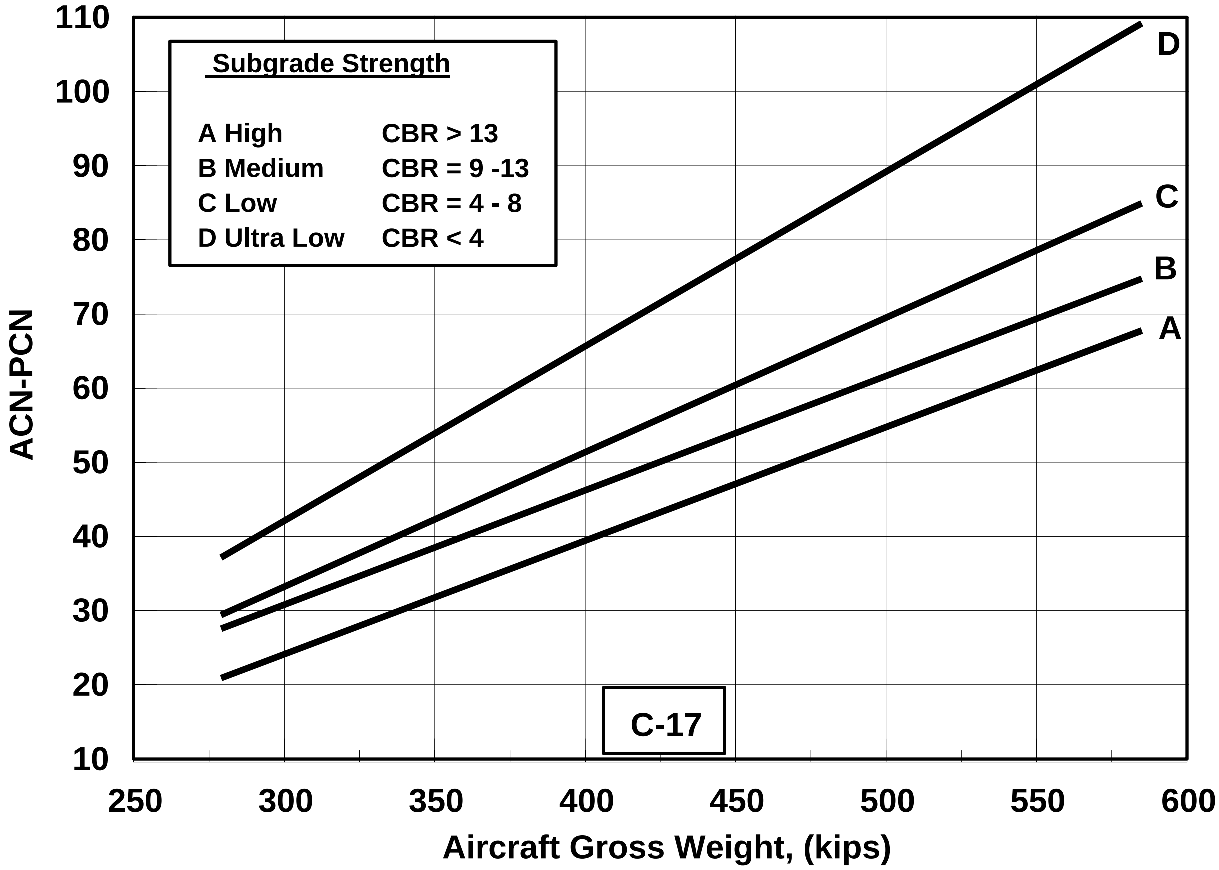


Figure C.12. Semi-Prepared ACN Curves for C-17

C.8.4. Similar ACN/PCN charts will be developed for other aircraft capable of using semi-prepared airfields. Figure C.13 depicts ACN/PCN curves for the C-130 aircraft and Figure C.14 depicts ACN/PCN curves for the C-27 aircraft. When analyzing the effect of an aircraft on a specific airfield feature, the appropriate ACN must be selected. For example, if the PCN of a given feature is 50/S/B/X/T, to determine the effect of any other aircraft on the same feature, the correct ACN for that aircraft must be used (the one considering similar pavement type and subgrade strength).

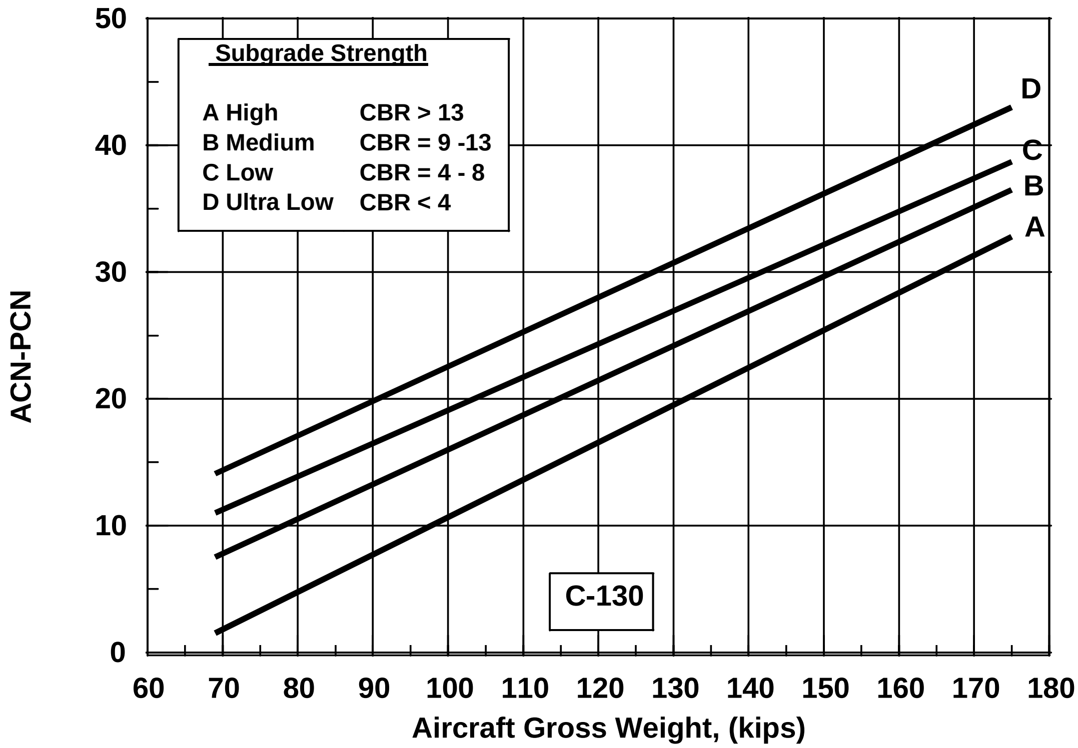


Figure C.13. Semi-Prepared ACN Curves for C-130

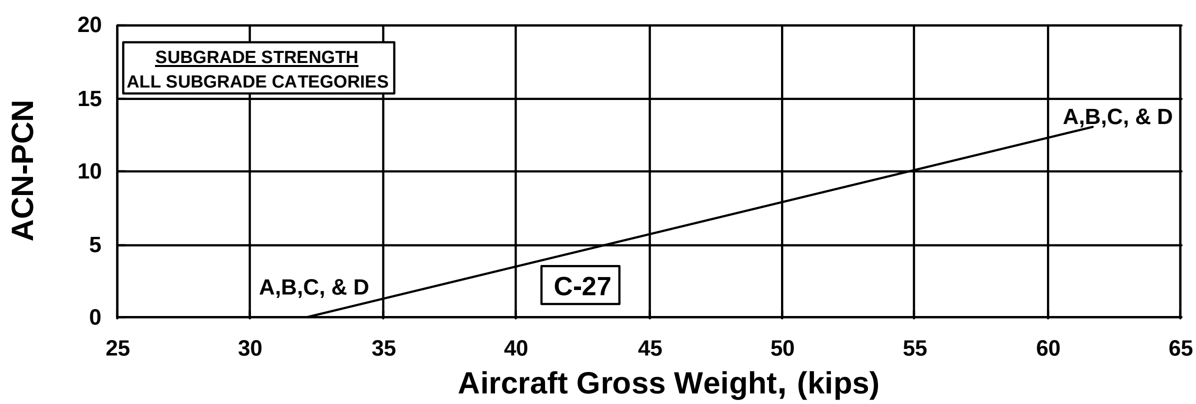


Figure C.14. Semi-Prepared ACN Curves for C-27

C.8.5. The ACN/PCN system is structured so that a feature with a particular PCN value can support an aircraft that has an ACN value equal to or less than the PCN. If the ACN is more than the PCN, the feature will be overloaded and the expected life reduced. Occasional minor overloading is acceptable and there will be situations when operators decide to overload the feature. Examples are emergency landings and short-term contingencies.

- Overload movements should not be allowed on pavements exhibiting signs of structural distresses or failure.

- For frost susceptible regions, overloading should be avoided during periods of thaw or when the subgrade appears weakened.
- For seasonally wet regions, overloading should be avoided if the subgrade appears saturated or weakened by water.

APPENDIX D

Friction Test Procedures for Contingency Operations

D.1. Introduction. This appendix presents the basic criteria and procedures used to determine whether a semi-prepared contingency airfield is suitable for C-17 operations in terms of surface friction characteristics and usable runway length. Appropriate data, figures, and evaluation charts are included. This appendix does not address structural suitability, load bearing capacity, operational geometrics, or airspace clearance issues.

D.1.1. Scope. The procedure described herein is an interim guideline for evaluating the friction characteristics of a semi-prepared contingency airfield. This appendix is organized into six sections that explain this friction test procedure:

- Selection of skid test vehicle
- Installation/Operation of Bowmonk
- Layout of field test locations
- Performance of skid tests
- Downloading/Processing of skid data
- Calculation of RCR (Runway Condition Rating) for C-17

These sections are shown graphically in Figure D.1.

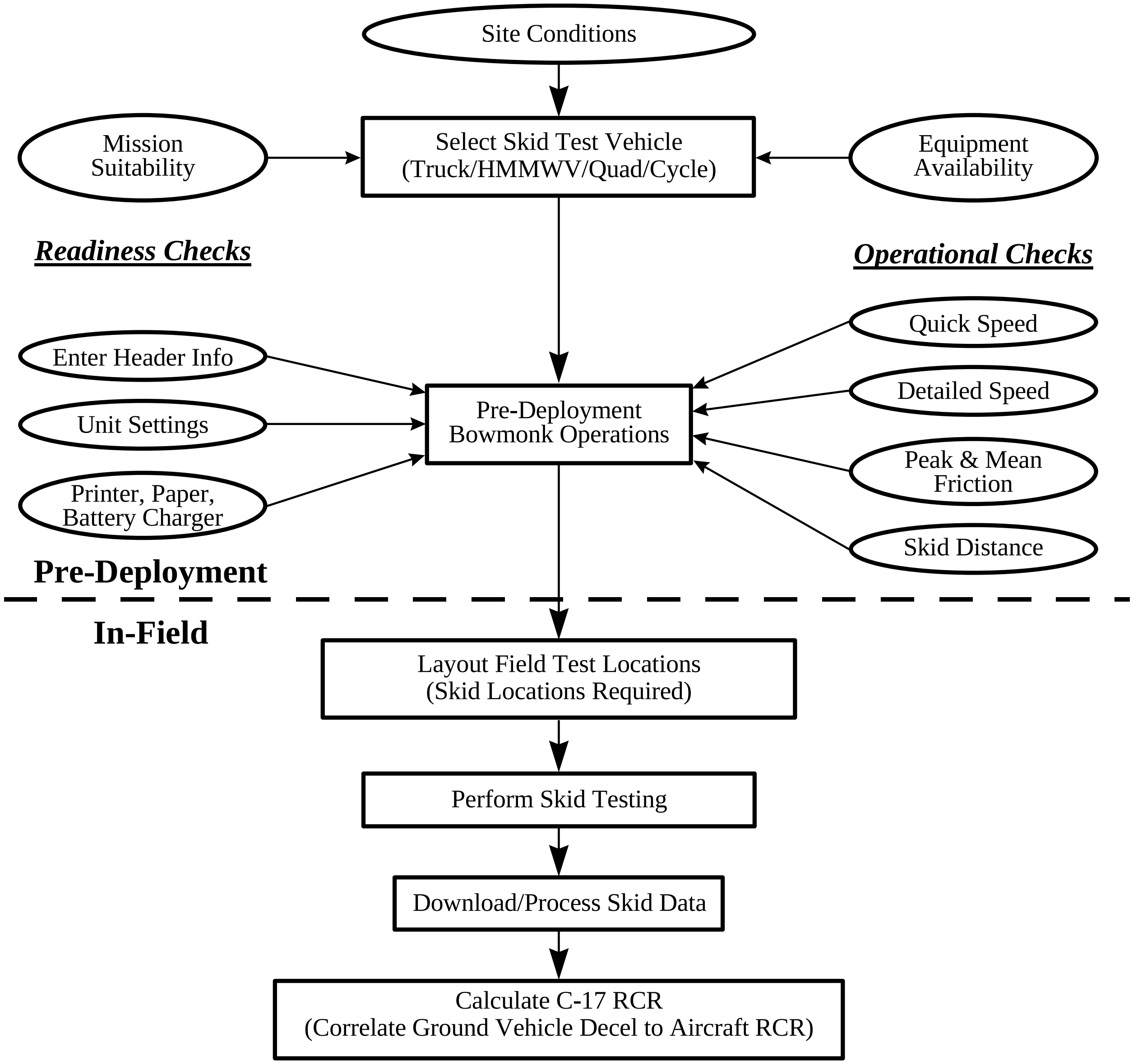


Figure D.1. Flowchart of the Recommended Friction Procedure

D.2. Select Skid Test Vehicle. The first step in this friction procedure requires the collection of deceleration (skid) data with a decelerometer unit mounted in a ground vehicle. Data was collected using the four vehicles most likely to be used to perform skid tests for C-17 deployment on contingency airfields: an Air Force six pax truck, a HMMWV (High Mobility Multi-purpose Wheeled Vehicle) with a communications pallet, a motorcycle, and a quad . The six pax truck is typically available to RED HORSE units and airfield pavement evaluation teams (APE), the HMMWV is available to Army Engineer Battalions, and the AFSOC Special Tactics Teams (STT) have access to the HMMWV, quad and cycle.

The ground vehicle selected should be one of these four vehicles since these particular vehicles were used to establish the initial data correlations to the aircraft. If a vehicle other than one listed above is used to collect data, the data correlation will not be valid. The mission commander must make the ground vehicle selection issue based on several factors, including: mission requirements, equipment availability, operational considerations, safety, and desired data accuracy. If the commander has the latitude to use any of these four vehicles, then the vehicle that gave the most accurate correlations to the aircraft should be used. These were (from best to worst): HMMWV, truck, quad, and cycle (all gave acceptable correlations, but there were differences in accuracy). Standard safety equipment should always be used by the test driver when performing these tests including seat belts and helmets. Since all the testing and the resulting correlations were done with the tire types shown in Table D.1 it is recommended that these same tires be used if at all possible. If it is not possible to use these same tires then at a minimum similar tire types and tread designs should be used. Detailed descriptions of each vehicle are provided in the following sections.

Table D.1. Nominal Tire Pressures, Tread Depth, and Make

Vehicle Type	Tire Pressure	Tread Depth (new)	Tire Make
HMMWV	20 psi +/- 2 psi	3/4”	Goodyear Wrangler R/T II 36 x 12.50 -16.5 LT load range C
Six Pax Truck	60 psi +/- 5 psi	15/32”	Goodyear Wrangler AT 235/85R16 m + s load range E
Quad (rear tires)	7.5 psi +/- 1 psi	18/32”	Dunlop KT645 AT 25 x 10 -12
Motorcycle (rear tires)	20 psi +/- 2 psi	13/32”	Dunlop K750A 4.60 - 17 4 P.R.

Note: Tires used should be in good condition with a tread depth at least half of that when new, with no flat spots or other abnormalities.

D.2.1. AFSOC-STT AN/MRC-144 (HMMWV). The AN/MRC-144 system is the combination of an M-998 HMMWV and an AN/GRC-206 communications pallet (see Figure D.2). The AN/MRC-144 HMMWV Package is the standard air traffic control (ATC) communication vehicle used by combat controllers from the SST. This HMMWV has a gross weight of approximately 6,600 lbs (5,500 lbs HMMWV and 1,100 lbs communications pallet). The communications pallet should be located so that it is directly behind the rear passenger seats (this was the configuration used in testing, some HMMWVs still have communications pallets located in a forward position where the rear passenger seats are). If a communications pallet is not located in the vehicle, then provisions should be made to securely place an equivalent amount of dead weight (sandbags, water tanks, etc.) in the same location. The HMMWV should be operated with the transmission in the high range, unlocked position.

D.2.2. Air Force Standard Six Passenger Pickup Truck (six pax). The six pax is a standard Air Force, six passenger, two or four wheel drive truck (see Figure D.3). The research testing was performed with a 4WD model (operated in the 2WD mode). Subsequent skid tests have been performed using both the 4WD and the 2WD models with no discernible difference in the test results.

D.2.3. AFSOC-STT Quad. The Quad is a 400cc, 4-wheel, 4WD vehicle used on assault zones by the STTs (see Figure D.4). The primary use for this vehicle is for rapid transportation of runway navigational aids and assisting in the establishment of the assault zone. The quad must be operated in 2WD mode for this friction procedure.

D.2.4. AFSOC-STT Motorcycle. The motorcycle is a national-stock-listed Kawasaki 250cc dirt bike (see Figure D.4). The motorcycle is modified with infra-red headlights, rifle racks, and equipment racks. Figure D.4 shows the motorcycle and the quad performing friction tests on a contingency airfield.

Figure D.2. HMMWV with Communications Pallet Performing Skid Test

Figure D.3. Air Force 6-Pax Truck Performing Skid Test (with C-17 in Background)

Figure D.4. Motorcycle and Quad Performing Friction Tests Simultaneously

D.3. Bowmonk Unit. The Bowmonk Airfield Friction Meter Mk II was the device used for this research testing. The use of any other device is not recommended since the data correlations were developed with this unit. The Bowmonk is manufactured in England and was designed to provide airfield managers with a simple, consistent, and automated method for predicting the available friction between the aircraft tires and runway surface. The unit was originally designed for use on paved runway surfaces, such as asphalt or concrete, but has now been evaluated for applicability to skid testing on semi-prepared contingency airfields. A skid test is performed with the decelerometer unit installed on a flat and level surface in the ground vehicle and the resulting ground vehicle deceleration measurement is used to predict aircraft stopping performance. In this section, the hardware will be discussed, the fundamental measurements will be described, specific installation recommendations will be provided, and procedures for testing and operating the Bowmonk will be detailed.

D.3.1. Hardware Description. The Bowmonk unit measures approximately 6 inches by 9 inches by 3 inches, and weighs only 6 pounds. It is relatively simple to operate and is portable for field use. The unit is battery powered and can operate for up to 16 hours in the field on a single charge. If necessary it may be recharged or operated with a 12 VDC cigarette lighter plug found in most vehicles. The Bowmonk includes a connection for exporting data via an RS-232 serial port to a personal computer for permanent storage and analysis.

The internal memory of the Bowmonk AFM-2 will hold up to 99 tests before it must be downloaded to a PC. A stripchart printer is provided for real-time hardcopy printouts of the data in the field. See Figure D.5 for a close up of the instrument panel of the Bowmonk unit.

D.3.2. Measurement Parameters. The Bowmonk measures the deceleration of the vehicle during a skid test. The values are reported as a percentage of the acceleration due to gravity (%g). Both peak and average (mean) calculated decelerations are provided, as well as calculated stopping distance, time of deceleration, and velocity at the start of the skid. This ground vehicle deceleration data can then be correlated to the required aircraft Runway Condition Rating (RCR) for comparing available runway length to stopping distance required by the aircraft.

D.3.3. Bowmonk Installation. In the HMMWV and six pax the Bowmonk unit is placed beside the driver and secured in a horizontal configuration. With the motorcycle and quad, the unit is placed on the equipment racks. The unit should be horizontal to within 15 degrees. The unit does not have to be perfectly level, since it has an internal software routine that compensates for small deviations from level. It will be necessary to construct plywood boxes to use the units with the six pax, quad, and cycle. The box for the six pax should be constructed so that it will hold the Bowmonk unit securely and allow the unit to be strapped in level on the front seat using the middle seat belt. Boxes for the quad and cycle should be constructed so that they hold the units firmly (so the units can be slid in and out of the boxes), and these boxes should be attached to the equipment racks with plastic wire/zip ties. Bungee cord should be placed across the top of the boxes and units to hold them securely in place. In the HMMWV, the unit should be placed on the level platform (front and center) between the driver and passenger seat and secured in a forward and down position with bungee cords. The unit must be placed so that the arrows on its lid are pointing forward in the direction of travel (to within 10 degrees). The unit does need to be securely fastened so that once it is installed, it will maintain its original position throughout the field tests, particularly with no forward or backward movement possible. The recommended mounting locations for each vehicle are shown in Table D.2. Figure D.6 provides a look at how the Bowmonk is installed in a HMMWV.

Table D.2. Recommended Mounting Locations for Bowmonk

Vehicle Type	Recommended Mounting Location
Six Pax	On the seat by the driver
HMMWV	Between driver and passenger, secured to platform
Quad	On front equipment rack
Cycle	On rear equipment rack

D.3.3.1. Bowmonk Operational Instructions. The following sections detail the operation and use of the Bowmonk during skid testing. The emphasis in these sections is on the procedures required to operate the unit. Detailed instructions on entering heading information, changing unit settings, and testing the unit for correct operation are given in the following sections. The manufacturer's documentation should be referred to for proper charging procedures, maintenance of the stripchart printer, and the installation and use of available software. The following steps detail the actions required to perform a test. Words in all uppercase are what the unit shows on the LCD display. Words in all uppercase and surrounded by brackets represent control panel keys.

- Turn unit on by pressing [RESET] , letting unit go through self check. Unit will display AFM2 READY once self check is complete.
- Press [A] to arm for first friction test. Check to be sure display shows ARM FOR TEST #1 ? (on first line), or whatever test number is being conducted. ENTER TO ACCEPT will be displayed on line two.
- Press [ENTER] to ACCEPT.
- The display will now show RUNWAY ID.
- Press and hold [ENTER] until unit beeps at least twice. Release [ENTER] button.
- Display will show PLEASE WAIT for several seconds.
- Then display will show ARMED FOR TEST #1 (first line). Second line will display SPEED = 0 .
- Accelerate smoothly until reaching desired test velocity.
- As vehicle accelerates, unit will indicate current speed.
- Apply full brakes (quad and cycle - rear brakes only) until vehicle comes to a complete stop.

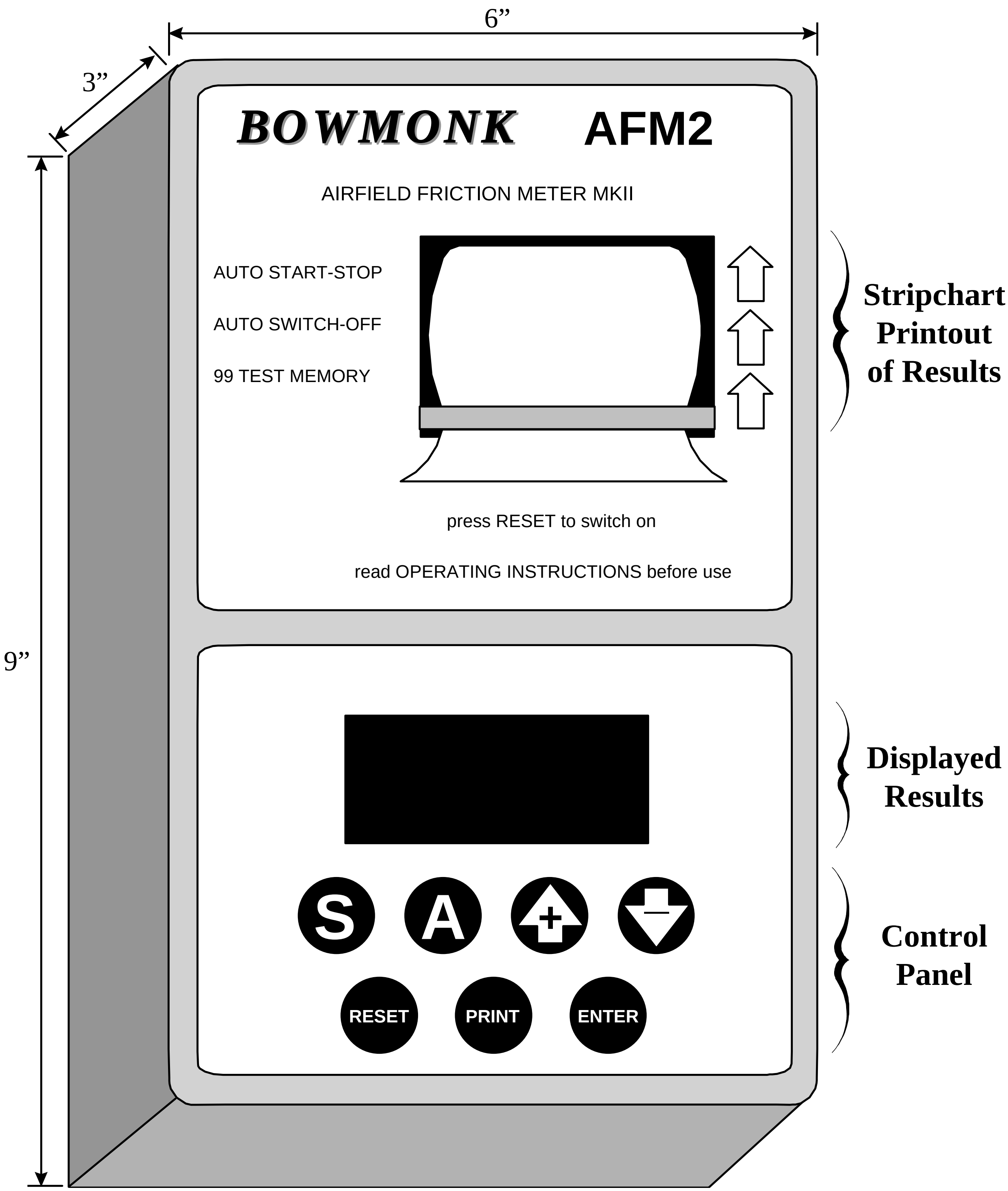


Figure D.5. Instrument Panel of the Bowmonk Unit

Figure D.6. Two Bowmonk Devices Installed in a HMMWV

- Unit will display DON'T MOVE - CALCULATING.
- Keep the vehicle stationary to allow unit to complete its internal calculations and display results.
- Unit will now display measured PERCENT G (first line) and SPEED (second line).
- If the results are acceptable, save the test results by pressing [A] to accept this test. The unit will now display AFM2 READY.
- If the result is not acceptable, press [RESET], the instrument will discard the current test and display AFM2 READY. Another test can be performed and saved with the same test number.
- Ready vehicle for next test and repeat from step 2 to perform subsequent tests.

Continue until desired number of friction tests are completed. The Bowmonk unit will automatically shut down after 4 minutes of inactivity to save the battery. To turn it back on, simply press [RESET], testing can then continue . To check the amount of memory used and the battery condition press and hold [RESET] once unit is on and displaying AFM2 READY. Release [RESET] to return to normal on state. This is recommended if large numbers of tests are conducted or battery is suspected to be low. Print out and/or download data if memory approaches full or battery level becomes low to avoid a loss of data.

D.3.3.2. Printing Test Results. After completion of the friction tests, the following steps are required to print out a summary of the test results. A results summary printout from a series of tests is shown in Figure D.7. Note that the friction values are the peak friction measurements (not mean). Also note that the overall average is an average of the peak friction measurements. The overall average peak friction value (63%g in Figure D.7) can be used in Table D.7 to calculate a C-17 RCR. However, an overall average mean friction value is highly preferable to a peak value for determining an RCR. The results are more consistent and the measurement is less likely to be made incorrectly.

- After completion/acceptance of last test, display will show AFM2 READY
- If unit has shutdown press [RESET] to turn unit back on.
- Press [PRINT] . The display will show PRINT TEST FOR RUNWAY ?
- (check the instrument and make sure it shows correct RUNWAY ID).
- Data may have inadvertently been collected under more than one runway id.
- The [UP ARROW] and [DOWN ARROW] can be used to select runway id to print.
- Press ENTER once (this will print a results summary stripchart report that shows the test number, the calculated velocity at braking, and the peak friction results for all tests performed.
- Remove stripchart printout, label with additional information if necessary (vehicle, driver, test conditions) and store in an appropriate place.

AIRFIELD FRICTION

Test	Friction %g	Time	Speed mph	Temp .C
1	57	20:35	22.7	
2	60	20:35	21.1	
3	57	20:36	20.3	
4	62	20:37	39.5	
5	64	20:38	40.3	
6	62	20:39	44.1	
7	64	20:41	54.7	
8	68	20:44	57.4	
9	65	20:46	58.3	
10	57	20:48	21.7	
11	58	20:48	21.8	
12	62	20:48	20.6	
13	64	20:50	40.3	
14	66	20:51	40.2	
15	66	20:52	41.9	
16	72	20:54	57.4	
17	70	20:56	60.6	
18	65	20:58	60.7	

1st 1/3 average 60 % g [-4 %]
2nd 1/3 average 62 % g [-1 %]
3rd 1/3 average 67 % g [6 %]

Overall Average 63 % g

Ground Temp: ____________

Runway ID: ALAMO__________
Examiner ID: HUMMER

Signature ____________________

Test 18 carried out 20:59 on 13-APR-97
Serial No: 11038 Next Cal: 10-FEB-98
Software Rev W3.12 Turnkey Instruments

Figure D.7. Example Stripchart Print Out

After the results summary is finished printing, it is possible to print out a more detailed results table. An example of this table is shown in Figure D.8. Note that the results table will show both the mean and peak friction, time to stop, brake delay time, speed, and stopping distance for each test.

AIRFIELD FRICTION

Test	Friction %g	Time	Speed mph	Temp C
1 ….	83	15:56	18.4	
2 ….	84	15:57	20.8	
3 ….	78	15:58	23.5	

1st 1/3 average	83	% g	[1 %]
2nd 1/3 average	84	% g	[3 %]
3rd 1/3 average	78	% g	[-4 %]
Overall Average	82	% g	

Ground Temp: ____________

Runway ID: ____________

Examiner: ____________

Signature ____________

Test 3 carried out 15:58 on 26-JUN-97
Serial No: 11039 Next Cal: 10-FEB-98
Software Rev W3.12 Turnkey Instruments

a. Results Summary.

RUNWAY FRICTION

Mean Deceleration: 66 % g
MAX over 0.20 sec: 78 % g

TIME TO STOP: 1.41 sec
SPEED AT BRAKING: 23.5 miles/hour
STOPPING DISTANCES: 21.3 feet

Ground Temp: ____________

Runway ID: ____________

Examiner: ____________

Signature ____________

RUNWAY FRICTION

Mean Deceleration: 71 % g
MAX over 0.20 sec: 83 % g

TIME TO STOP: 1.32 sec
SPEED AT BRAKING: 20.8 miles/hour
STOPPING DISTANCES: 19.5 feet

Ground Temp: ____________

Runway ID: ____________

Examiner: ____________

Signature ____________

RUNWAY FRICTION

Mean Deceleration: 68 % g
MAX over 0.20 sec: 83 % g

TIME TO STOP: 1.22 sec
SPEED AT BRAKING: 18.4 miles/hour
STOPPING DISTANCES: 15.8 feet

Ground Temp: ____________

Runway ID: ____________

Examiner: ____________

Signature ____________

Test 1 carried out 15:57 on 26-JUN-97
Serial No: 11039 Next Cal: 10-FEB-98
Software Rev W3.12 Turnkey Instruments

b. Results Table.

Figure D.8 Example Printouts of Friction Results

To print out a results table, continue with the following steps:

- Press [PRINT] for a second time.
- Use [UP ARROW] or [DOWN ARROW] to select test number to print.
- Press [ENTER] to start printing a results table for that test number.

All the tests stored in the unit can also be printed. The following steps can be used to print the results tables from the test number indicated on the unit up to the last test carried out.

- Unit will display PRINT TEST N.
- Press [A] instead of [ENTER] as described in the steps above. This only applies to a results table printout.
- Unit will print results tables from test N up to the last test carried out.
- Press [RESET] at anytime to terminate printout.

See Figure D.8-b (Results Table) printout for an example. Note that both peak and mean values are given for each test. If using the mean friction value measurements to determine a C-17 RCR, then the average for all the means must be calculated. After performing the skid tests in the number and manner described elsewhere in this appendix, a results table must be printed out for each test. Total the mean values for each test then divide that total by the number of tests to determine the overall average mean friction value for that series of tests. As an example, look at the data shown in Figure D.8-b (Results Table). The three mean friction values are 66%g, 71%g, and 68%g. The total value is 205%g. Divide 205%g by a total of three tests for an average mean value of 68.3%g for this series of tests. This overall average mean friction value is the number that is used in Table D.7 to calculate a C-17 RCR. An overall average mean friction value is highly preferable to an overall average peak friction value for determining a C-17 RCR.

D.3.3.3. Download Skid Data. The following procedure is to be used for uploading data from the Bowmonk Mk II Airfield Friction Meter to a field laptop or portable computer. This procedure is not critical to contingency airfield operations, but it does preserve the data collected in more detail and allow for a more in-depth analysis of the data later if necessary. Field computer must meet these minimum requirements : 386SX processor, at least 4 MB of RAM, a hard disk with at least 4 MB of free space, one RS232 serial port, VGA or SVGA screen, a mouse, and Microsoft Windows 3.1 or later. The manufacturer supplied program (AFM2 for Windows) must also be installed on the field computer. Note that only the software and Bowmonk units purchased together are compatible due to the encoding of serial numbers on the units and software. Units and software purchased separately will not work.

- Attach manufacturer supplied download cable to both Bowmonk and RS232 serial port of computer.
- Press [RESET] on Bowmonk to turn on if not already on.
- Press and hold [RESET].

- Unit will display battery voltage and percent memory used. If percent memory used is greater than 95%, then unit should not be downloaded (doing so will cause software to crash and will corrupt computer database, resulting in loss of data and requiring re-installation of software).
- If data in Bowmonk has not been printed, it should be done now (in case of downloading problems).
- If memory used was > 95%, then unit must be cleared and tests redone.
- Start up "AFM2 for Windows" program in Windows on the laptop computer.
- Note the serial numbers that are displayed when program starts up. Check to see if the unit you wish to download matches one of these numbers The serial number of the unit is located on the bottom of the test summary strip chart printout. If not then data cannot be downloaded.
- Click on OK button on windows program to start it.
- Click on UPLOAD button to begin process of uploading.
- During the upload do not disturb the computer, Bowmonk , or connecting cable.
- Once uploading is complete, access and browse through database to ensure that the recently collected test data has downloaded.
- Exit database. If another unit is not going to be downloaded immediately, then exit completely from the AFM2 program. If the AFM2 program remains running and the computer suffers from a glitch, lockup, or shutdown due to sleep mode or low battery, the database will be corrupted, resulting in loss of data and requiring re-installation of software.
- Disconnect cable and shutdown both the Bowmonk and computer to save power if they are not going to be used immediately.
- Reset unit to prepare for next series of tests.

D.3.3.4. Clearing and Resetting Bowmonk. The following steps are required to ready the unit for the next series of tests. This procedure will clear out all the test results collected so far. Unit settings will not be affected by this procedure.

- Press [RESET] to turn unit on if not already on.
- Display will show AFM2 READY.
- Press [ENTER] to enter Editing Mode.
- Use [UP ARROW] and [DOWN ARROW] to move between menus.
- Move to CLEAR MY MEMORY? menu.
- Press [ENTER].
- Unit will display ALL RECORDS LOST?, PRESS [ENTER] TO ACCEPT, [RESET] TO ESCAPE.
- Press [ENTER] to clear memory.
- Unit will display AFM2 READY.
- Press [S] and [PRINT] at the same time to turn unit off.

D.3.4. Predeployment Operational Checks and Procedures. The following sections detail procedures that can be performed as predeployment steps to save time in the field or verify proper functioning of unit before actual deployment.

D.3.4.1. Entering Header Information. This section details the steps necessary to enter "Header" information in the Bowmonk unit. This can be done before arriving on site to save time in the field. The unit will retain this information until it is changed. Entering this information is useful for data documentation but not necessary for proper operation of the unit.

- Press [RESET] to turn unit on if not already on. Unit will display AFM2 READY.
- Press [ENTER]. The display will show EDITING MODE.
- Press [UP ARROW] and the display will show EXAMINER ID.
- Press [ENTER] again. You may now enter the Examiner ID.
- Use the [UP ARROW] and [DOWN ARROW] to select a letter.
- Press [ENTER] to accept that letter and move to the next letter.
- Press and hold [ENTER] when Examiner ID is correctly input.
- The display will now show RUNWAY ID.
- Press [ENTER] again to enter the Runway ID.
- Use the [UP ARROW] and [DOWN ARROW] to select a letter.
- Press [ENTER] to accept that letter and move on to the next letter.
- Press and hold [ENTER] when Runway ID is correctly input.
- The display will show NAME OF AIRPORT.
- Press [ENTER] again to enter the Name of Airport
- Use [UP ARROW] and [DOWN ARROW] to select a letter.
- Press [ENTER] to accept that letter and move on to the next letter.
- Press and hold [ENTER] when Name of Airport is correct.
- Press the [RESET] . The display will now read AFM2 READY.

D.3.4.2.1. Bowmonk Configuration Menus. The following sections detail the steps necessary to access and modify important unit settings. These settings should not be modified unless they differ from settings recommended in this appendix. It should not be necessary to perform any of these modifications. This section is included mainly to document these settings and provide a way for the user to check them should the unit not appear to be operating correctly. Each Bowmonk unit comes with a manufacturer supplied password. This is to prevent inadvertent changes to important unit settings which is possible (without a password) due to the nature of the control panel. It is highly recommended that the password for the unit be documented and stored in multiple locations and accessible in the field. Some settings cannot be modified or even checked without the password. Anyone using the password to check or modify settings should use caution and document any setting numbers before and after any changes. The manufacture's user manual should also be consulted. If the correct password is given to the Configuration Prompt in the Editing Mode, the following menus appear:

a) Advanced Setup
b) Trim Parameters
c) Trim Zeros
d) Adjust Clock
e) Re-Calibrate

These menus allow the setup of the instrument to be changed. Use [UP ARROW] or [DOWN ARROW] to move between the menus and press [ENTER] to select. These settings might have to be re-entered if the unit experiences a power loss. A brief description of each follows.

D.3.4.2.2. Advanced Setup. This option allows the user to turn various Bowmonk unit settings ON or OFF. See appendix A in the manufacturer's manual, *Bowmonk Airfield Friction Meter MK2 Operating Instructions*, for details on selecting desired settings.

D.3.4.2.2.1. Trimmable Parameters - Bowmonk Default Settings Required. Probably the most significant of these menus is the Trim Parameters menu. These are the configuration settings that were used for the research testing. All the correlations in this appendix are based upon results obtained using the BOWMONK with these settings. Therefore, the Bowmonk unit must be set with these defaults. The following sections describe these settings. See appendix B in manufacturer's manual for details on editing or modifying these values.

Table D.3. Required Values for Trimmable Parameters

Setting	Required Value
Tilt:	2.5 degrees/g
Brake:	10.00%
Starting:	00.50 secs
Stopping:	00.10 secs
PFT Trig:	20.00 N
MAX over:	0.20 s

D.3.4.2.2.2. Tilt. This compensates for the forward tilt of the vehicle as it decelerates (movement of the suspension). Vehicles with softer suspensions require a larger tilt compensation value and conversely, harder suspensions a lower tilt value. The default value of 2.5 (which simulates a typical car) was used for all research testing.

D.3.4.2.2.3. Brake. This is the deceleration in %g of the Braking Threshold which determines the start and end of braking. If the External Trigger is being used, it is also the threshold for the end of the Brake Delay Time period. It can be adjusted between 00.00% and 99.99% g. The default value is 10.00% g.

D.3.4.2.2.4. Starting. The time window of the deceleration must be sustained at more than the braking threshold for the braking to be determined to have started (and the Brake Delay to have ended). The brake start time is then taken as the beginning of this time window. The time from the External Trigger to the brake start time is the Brake Delay Time. The Starting Time Window can be adjusted between 00.00 sec and 02.55 sec, the default value is 00.50 secs.

D.3.4.2.2.5. Stopping. The time window (after a valid start) of the deceleration must be sustained at less than braking threshold for the braking to be determined to have ended (and the vehicle to have stopped). The brake end time is then taken as the beginning of this time window. The time between the brake start and brake end times is the Braking Time. The average deceleration will be calculated over this interval unless you have specifically included in the average the deceleration during the Brake Delay Time as well. The Stopping Time Window can be adjusted between 00.00 sec and 02.55 sec, the default value is 00.10 secs.

D.3.4.2.2.6. PFT Trig. This is the brake pedal force in Newtons required to trigger the instrument when using the pedal force transducer. Not applicable to the Bowmonk AFM2 model unit.

D.3.4.2.2.7. Max Over. The time window interval in seconds over which the developed or sustained peak friction reading is determined. This setting will cause the friction value to be the greatest lowest value seen as the window is scanned across the data.

D.3.4.2.3. Trim Parameters. The Bowmonk unit is programmed with some adjustable parameters whose values can be changed. This editing option allows their value to be changed.

D.3.4.2.4. Trim Zeros. This menu allows the user to periodically check and trim the transducer zero levels. Zeroing can be done on any flat surface by following the prompts on the display. Properly trimmed zeros allow the instrument to be used to make accurate measurements of ground slope. Note that the zero trimming surface does not have to be exactly horizontal but it must be flat. Make the first measurement with the instrument handle nearest to you, then rotate the instrument through 180 degrees and make the second measurement with the handle pointed away from you.

D.3.4.2.5. Adjust Clock. This menu allows the time to be changed to compensate for daylight savings time. On selection, the minutes value will flash to indicate it can be adjusted, press [UP ARROW] or [DOWN ARROW] to change, then [ENTER] to save the new value. The hours value will then flash and can be adjusted likewise. The date can only be changed at the factory.

D.3.4.2.6. Re-Calibrate. Shows the latest calibration information and allows the factory/distributor to re-calibrate the instrument. Press [P] to print a calibration report. Calibration reports are supplied by the manufacturer when a unit is purchased or re-calibrated. Copies of this report should be made and stored in appropriate locations for future reference. Units must be shipped back to manufacturer once a year for yearly calibration.

D.3.5. Operational Checks. The following sections detail procedures that can be performed before or after deployment if necessary to verify proper operation of the Bowmonk unit. These are recommended as predeployment activities due to the length of time and manpower required to perform these tests. These tests are also useful for operators who need to become familiar with the operation and accuracy of these units.

In the process of performing these procedures, all safety considerations and vehicle skidding procedures described in this appendix should still be followed.

D.3.5.1. Quick Verification of Speed Measurement. For this operational check, a long, flat, level area is required. The Bowmonk unit is placed in the vehicle of choice as recommended. The unit is armed and operated as normal. Make sure the unit displays a speed of 0.0 when starting and that the vehicle is accelerated smoothly and uniformly. As the vehicle increases in speed towards the target speed, the driver watches the speed as displayed on the Bowmonk (this is impossible on the cycle, and in the HMMWV and six pax a passenger to observe the unit is helpful). If when reaching target speed the difference between the speedometer and the Bowmonk is less than 5% then the unit is likely working correctly. Multiple units can also be used simultaneously to make comparisons between Bowmonk units. This test assumes that the vehicle speedometer is accurate and functioning correctly.

D.3.5.2. Detailed Verification of the "Speed" Measurement. For this operational check, a long distance must be measured out on flat, level ground (at least 1000') with large physical markers placed at either end (such as cones, flagging, or airfield distance markers). The distance should be measured to an accuracy of 1% (1000’ +/- 10’ or 4000’ +/- 40’ for example). The distance between 1000' markers on most airfields is not always exactly 1000.0', so it is important to verify this accurately. The driver then accelerates the vehicle to the target speed and maintains the vehicle at this constant speed for at least 2 seconds to stabilize the vehicle speed. The driver then uses a stopwatch (accurate to at least 0.1 sec) to time how long it takes to traverse this known distance. The marker time measurements should be made to within 0.25 seconds and a passenger to make the timing measurements is helpful. The driver should maintain as constant a speed as possible over the length of the timing course by watching the odometer closely. This total distance in feet is divided by the time to cover that distance in seconds, to obtain a velocity in feet per second. This velocity in feet per second is then converted to mph by multiplying the speed in feet per second by 0.6818. After the driver passes the second timing marker, then a skid test is performed. The skid test must be of high quality, i.e. a smooth, level skid with little vehicle bounce, with the vehicle ending straight for this operational check to be made (see section on skid test procedures and requirements). The speed calculated from the time to traverse the measured distance is the actual velocity. This actual velocity is then compared to the odometer indicated velocity and the Bowmonk measured velocity. If the percent difference between these three ways to measure velocity is less than 5%, then the Bowmonk "speed" measurement is accurate. Multiple tests may be performed and the average of all the tests for each measurement technique may then be compared. This test measures the accuracy of the speedometer as well as the Bowmonk.

D.3.5.3. Verification of Peak Friction or Mean Friction Measurement. For this procedure, simply run two or more Bowmonk units (if available) simultaneously in the desired vehicle (this will only work on the HMMWV or truck, the cycle and quad do not have enough room). Perform at least three skid tests at the target speed for that vehicle and then compare the average results. Either peak or average (mean) friction measurements may be compared. If the overall average between units differs by less than 3%, then the units are most likely reading correctly. If the averages differ by more than 3% then more tests should be conducted. If a large number of tests are conducted and the overall average between units still differ by more than 3%, then one or more units may be malfunctioning. Check to see if the unit settings are the same and that none of the units is due for its annual calibration.

D.3.5.4. Verification by Direct Measurement Of Skid Distance. This procedure may be used to directly measure the average braking friction of any vehicle used. Direct comparison of measured skid distance (or this number converted into an average(mean) friction) with the values calculated by a Bowmonk unit may be used to perform an operational check. In addition, this procedure can be used to determine the contingency airfield friction (and C-17 RCR) if a Bowmonk unit should not be available, or is functioning improperly. The most to least preferable vehicles for this testing are still the HMMWV, six pax, quad and cycle. The following steps are required to perform this operational check.

1. Perform safety checks.
2. Review skidding procedure.
3. Review Bowmonk settings and operational sections if checking Bowmonk for proper operation.
4. Install Bowmonk unit in chosen vehicle if checking unit for proper operation.
5. Identify a long, smooth, level area to perform skid test. If performing this procedure in lieu of Bowmonk measurements at a contingency airfield line up at appropriate location to perform the next skid test .
6. Place marker at chosen area (orange cone, flag, etc.) and observer if available.
7. Observer should be at marker position, the same longitudinal distance down the runway, but a safe distance laterally displaced (50 feet left or right of skid location).
8. Select appropriate test speed, considering operational, equipment, and safety factors. Higher speeds (40 mph or greater) are preferred as they are more accurate.
10. Setup Bowmonk unit for normal operation, if applicable.
11. Begin acceleration as per normal skid procedure.
12. Driver accelerates down runway towards marker, reaching and maintaining selected test speed as accurately as possible.
13. Driver performs standard braking procedure when front tires are even with marker. Remember that for the quad and the motorcycle that only the rear brakes are to be used for braking (no front brakes).
14. Driver remains stopped and operates Bowmonk unit (accepting or rejecting data) as necessary.
15. If testing Bowmonk unit, the vehicle must be straight to within approximately 15 degrees of original direction of travel. If greater than 15 degrees repeat test.

16. Observer notes where braking actually begins and if braking wheels locked up resulting in a true skid. If braking wheels did not appear to lock up, repeat test.
17. Locate point on runway where rear tires actually began skidding.
18. Observer and/or driver measure the point from where braking of the rear tires began to the point where the rear tires are located when the vehicle came to a complete stop.
19. Distance is measured in feet. Most preferably with survey wheel or survey tape.
20. Record vehicle used and skid distance in feet.
21. Locate measured distance in column one of Table D.4. Round up to next higher distance if measurement falls between two values.
22. Move horizontally along that row until column for speed at which test was conducted is located.
23. This number is the average(mean) friction (in percent g) that the test vehicle experienced. Record this number.
24. Repeat test procedure if performing more than one test. Ready vehicle for next skid test if collecting data in lieu of Bowmonk measurements.
25. If this was last test, print out Bowmonk data and download data if necessary.

Once the test or tests are completed, the average(mean) friction as measured by the Bowmonk can be compared with the average(mean) friction derived from table D-4. If these values differ by less than approximately 5%, the Bowmonk unit is probably functioning correctly. If the values differ by more than 5%, check to see if the unit settings are correct and that the unit is not due for its annual calibration. It may be desirable to perform multiple tests and compare the average results of the sequence of tests. If performing these tests as a substitute for actual Bowmonk measurements, standard skidding procedures, skidding locations, and data analysis must still be followed.

Table D.4. Average Friction vs Braking Distance

Stopping Distance (feet)	20 mph	30 mph	40 mph	50 mph	60 mph
15	90	NA	NA	NA	NA
20	67	NA	NA	NA	NA
25	54	NA	NA	NA	NA
30	45	101	NA	NA	NA
35	38	86	NA	NA	NA
40	34	76	NA	NA	NA
45	30	67	NA	NA	NA
50	27	61	NA	NA	NA
55	24	55	98	NA	NA
60	22	50	90	NA	NA
65	21	47	83	NA	NA
70	19	43	77	NA	NA
75	18	40	72	NA	NA
80	17	38	67	NA	NA
85	16	36	63	99	NA
90	15	34	60	93	NA
95	14	32	57	88	NA
100	13	30	54	84	NA
105	13	29	51	80	NA
110	12	28	49	76	NA
115	12	26	47	73	NA
120	11	25	45	70	NA
125	11	24	43	67	97
130	10	23	41	65	93
135	10	22	40	62	90
140	10	22	38	60	86
145	9	21	37	58	83
150	9	20	36	56	81
155	9	20	35	54	78
160	8	19	34	53	76
165	8	18	33	51	73
170	8	18	32	49	71
175	8	17	31	48	69
180	7	17	30	47	67
185	7	16	29	45	65
190	7	16	28	44	64
200	7	15	27	42	61

Note: Values in table are in units of percent g.

Table D.4. Average Friction vs Braking Distance (Continued)

Stopping Distance (feet)	20 mph	30 mph	40 mph	50 mph	60 mph
210	6	14	26	40	58
220	6	14	24	38	55
230	6	13	23	37	53
240	6	13	22	35	50
250	5	12	22	34	48
275	5	11	20	31	44
300	4	10	18	28	40
325	4	9	17	26	37
350	4	9	15	24	35
375	4	8	14	22	32
400	3	8	13	21	30
425	3	7	13	20	28
450	3	7	12	19	27
500	3	6	11	17	24
550	2	6	10	15	22
600	2	5	9	14	20
650	2	5	8	13	19
700	2	4	8	12	17

Note: Values in table are in units of percent g.

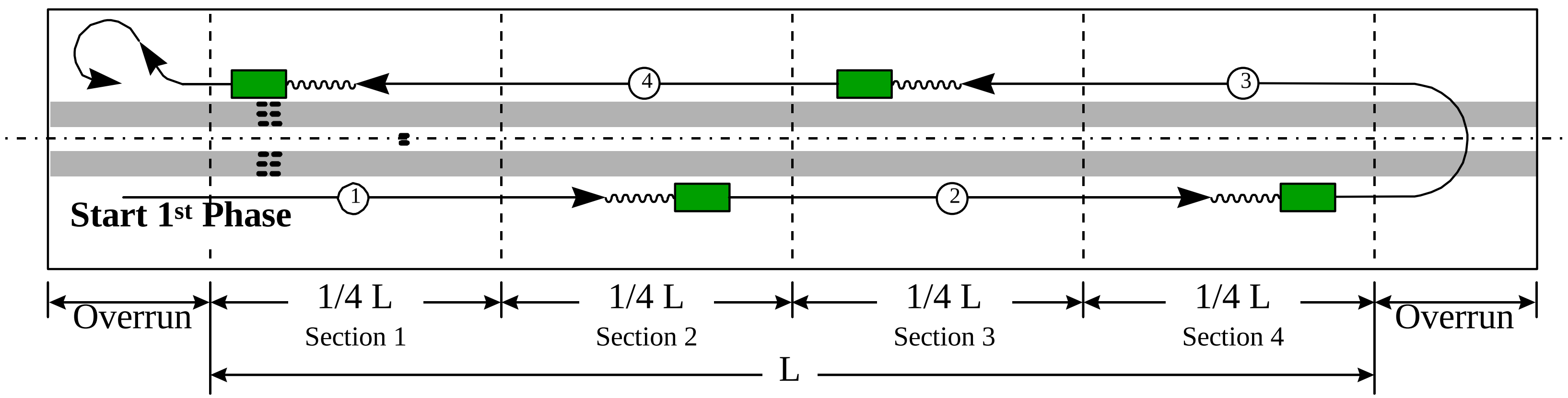
D.4. Layout Field Test Locations. The goal of the field tests is to accurately measure the surface friction characteristics of the contingency airfield. In order to meet this goal, an appropriate number of skid tests must be conducted at multiple locations on the airfield. When conducted in the correct manner at the appropriate locations on the airfield these tests will provide an accurate measure of the airfield surface friction. These measurements can then be converted into a C17 RCR. The following sections detail skid testing patterns on the runway, number of tests required, and procedures for performing skid tests.

D.4.1. Skid Test Locations. Mark the beginning of the overruns at each end of the airfield. Place markers at the midpoint of the airfield and then at the 1/4 points so that the airfield is divided into 4 test sections (see Figure D.9). **As shown in Figure D.9 the skid testing should be conducted just outside the C17 wheelpaths to either side.** The skid vehicles, though much smaller than the aircraft, can prematurely degrade the runway surface and potentially reduce the available friction. The distance between the C-17 main tire groups is approximately 25 feet. With the aircraft on the centerline, the center of the wheelpaths are about +/- 12.5 feet from the centerline. The width of each main group of 6 tires is 7.5 feet, adding another 4 feet for a total of +/- 17 feet to the outside edge of either tire group. Allowing another 10' for lateral wander of the aircraft between landings the inside edge of the skid vehicle should then located +/- 27 feet from the centerline. Since the four wheeled skid vehicles have a 6 foot wheel base , the center of the skid vehicle should be located +/- 30 feet from centerline during a skid. If possible the driver should perform each skid test on a "virgin" section of runway (one that hasn't been skidded on yet). This can be done by skidding a little further up or down the runway or moving the vehicle sideways 2 to 3 feet if two runs have to be made in approximately the same location. The actual skid locations, patterns, and sequences are not critical to the friction testing procedure. Much more important is that the areas on which skid tests are performed are representative of the runway surface that the aircraft itself will use for braking.

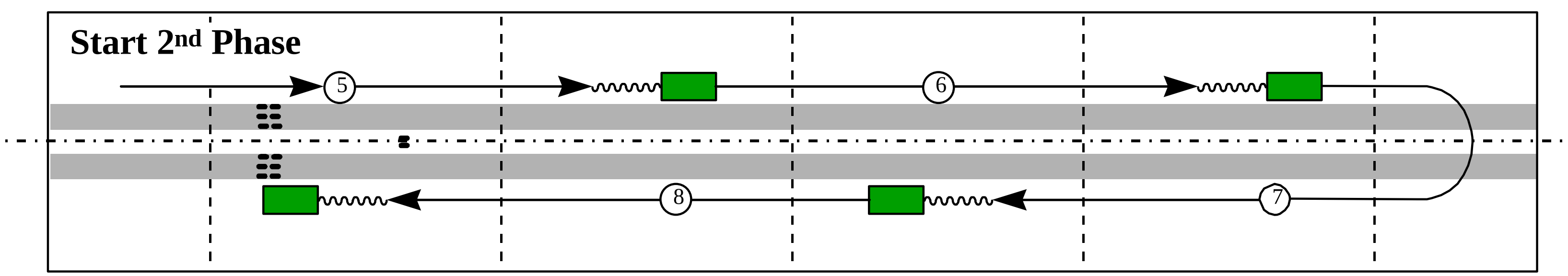
D.4.1.1. Runup Lengths and Stopping Distances. There are required runup lengths for the test vehicles. The evaluator should think through the recommended test sequence and pattern after arriving on site and carefully plan the skid test locations to achieve maximum data collection efficiency and avoid aborted test runs due to inadequate runup distance between skid locations. Assuming test speeds of 40 mph for all vehicles, Table D.5 is provided.

Table D.5. Required Runup Distances (at 40 mph)

Runup Skid Vehicle	Length Required	Maximum Required Stopping Distance (ft)
HMMWV	1400	300
Truck	1200	250
Quad	1000	175
Cycle	700	125



(a) Phase 1 - First Half of Minimum Run



(b) Phase 2 - Second Half of Minimum Run.

Test Number, Direction and Skid of Vehicle

LEGEND:

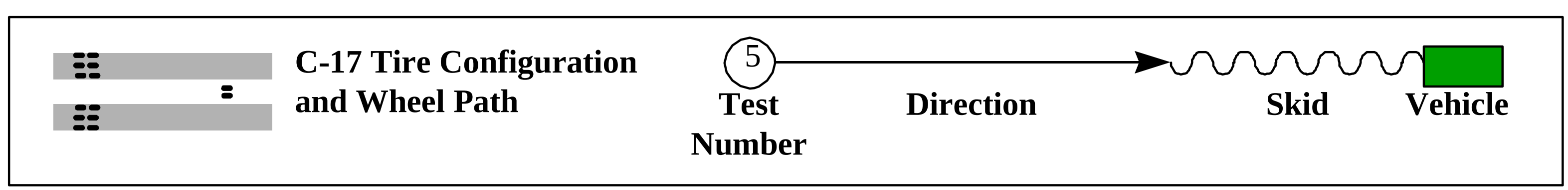


Figure D.8. Skid Test Locations and Pattern

Note that if the approach ends of the runway provide extra runup room (in addition to the 500-foot overruns), they can be used if they allow for smooth, uniform acceleration. Overruns can be used for vehicle acceleration but should not be used for skid testing.

D.4.2. Number of Tests Required. Preliminary analysis of the research data has determined the number of tests required for a typical contingency airfield evaluation (4000'x90' as an example), as shown in Table D.5. Times shown in Table D.6 are only approximate and can vary highly depending on vehicle type, vehicle condition, length of runway, driver technique, and data collection efficiency.

Table D.6. Number of Tests Required

Number of Tests	Confidence Level	Time to Complete
8	Minimum Required	20 minutes
16	Standard	35 minutes
24 or more	Desired	50 minutes or more

D.4.2.1. Minimum Number of Tests. The minimum number of tests required is 8. The airfield evaluator should perform these tests in the approximate locations as shown in Figure D.9 . To perform this minimum number of tests the driver conducts skid tests 1 through 4 at the locations shown in Figure D.9 (a). The driver then conducts skid tests 5 through 8 at the locations shown in Figure D.9 (b). The skid locations shown within each section are just guidelines. It is preferable to skid in the center of each section but if runway length or vehicle performance require skidding elsewhere that is acceptable, as long as a skid remains in the appropriate section. For extremely short runways the driver may back the vehicle up after a skid to allow more runup distance for the next skid.

D.4.1.2. Medium Confidence Level. A more accurate answer will result from the evaluator performing 16 tests. To perform this larger number of tests, conduct the procedure described in Section D.4.2.1. twice; reversing direction on the second set. This insures that an even number of tests are conducted in either direction. This helps to compensate for the effects of the wind on the friction measurements.

D.4.1.3. High Confidence Level. The most accurate results will be achieved if the evaluator has the time to perform 24 or more skid tests. The driver repeats the two test patterns shown in Figure D.9 (reversing direction after each subset of 8 tests) until the total number of tests reaches the desired number. With the test pattern shown, 24 or 32 tests can easily be performed. It is unnecessary to collect more than 32 tests.

D.5. Perform Skid Testing. The following section lists the general steps required to perform one friction test at one skid location. **Any of the following items in bold are extremely important and must be followed for the test to be accurate.**

1. Align test vehicle with runway on one of the two longitudinal test lines shown in Figure D.9. **Both vehicle and tires should be straight.**

2. Arm Bowmonk unit for test. Device should be armed just prior to vehicle acceleration. **If unit is armed and a delay of more than 15 seconds occurs, unit should be reset and then rearmed**.
3. **Begin vehicle acceleration smoothly but quickly. Acceleration should be uniform without spinning tires or excessive vehicle bounce**. Proceed down runway, accelerating uniformly to target test speed.
4. Once test speed has been reached, maintain uniform speed for 2 sec.
5. Perform skid test. Apply **full**-**braking** until coming to a **complete stop**. Remember **full rear braking only** for quad and cycle.
6. Bring vehicle to a complete stop. **Vehicle and driver MUST remain still for several seconds while Bowmonk unit calculates and records braking information.**
7. Check test results in the Bowmonk display.
8. If data appears valid, **accept test**. If data appears invalid reject and repeat test.
10. Ready Bowmonk for next skid test.

If data appears invalid, reject test, return to previous starting location and repeat steps 1 through 8. If vehicle is not properly aligned with the runway after skidding to a stop (wheels pointed straight ahead) then pull forward and align vehicle and wheels for next skid. Several of the above steps are discussed in greater detail in the following sections.

D.5.1.1. Target Speed at Braking. The following target speeds are recommended for operational skid testing: 60 mph for the HMMWV and six pax, 50 mph for the quad and cycle. Please note that the cycle may not have a speedometer or tachometer, so the operator must establish speed when using this test vehicle. If the cycle speed is correct to within +/- 10 mph an adequate deceleration value will be measured. With all vehicles, the driver should attempt to obtain correct target speed within reason. However, attempts to maintain proper speed should not override other considerations described in this appendix which are required to perform testing properly.

D.5.1.2. Braking Procedure. The correct braking procedure is to apply full braking until completely stopped. **For the HMMWV and six pax, this means pushing on the brake pedal as hard as possible to lock up all four tires and then skidding to a complete stop. For the cycle and quad, it is unsafe to lock up both the front and back brakes so the procedure requires locking up the back brakes only**. **Full-braking must be used for operational testing**. Note: Warm up test skids should be performed, starting at lower test speeds and using non-skid braking (partial braking) to confirm proper braking action and determine vehicle braking behavior at the particular airfield.

D.5.1.3. Steering During Skids. During the skids, a nominal amount of steering will be required to maintain as straight a line as possible. This is acceptable and will not significantly affect the test results. **If the vehicle twists more than +/- 15 degrees from a longitudinal line, then the test must be repeated.**

D.6. Calculate C-17 RCR. There are three ways to calculate the Runway Condition Rating (RCR) value required for C-17 contingency operations:

- Convert Bowmonk “Mean Deceleration” readings into RCR
- Convert Soil Type to RCR
- Convert Ground Vehicle Skid Distance Measurements to RCR

D.6.1. Convert Bowmonk “Mean Deceleration” Readings into Aircraft RCR Values. This section describes the first method, which is by far the most accurate. Data collected with the Bowmonk can be used in Table D.7 to convert the friction measurements into an equivalent C17 RCR. The mean deceleration measurements are used to calculate an overall average mean value. This average value is compared to the values in column two (mean) and the appropriate C17 RCR value is determined.

D.6.2. Alternate Friction Prediction Procedures. There are two alternate friction prediction procedures: correlating the soil type to RCR, and directly measuring the skid distance with a ground vehicle and correlating to RCR. Of the two alternate procedures, measuring the skid distance is more accurate, and is preferred over correlating RCR to soil type only.

Table D.7. Stopping Friction Guidance (Preliminary)

Semi-prepared Runway	Surface Condition	HUMVEE Bowmonk Reading (at 40 mph)*	RCR
Unstabilized	Visibly dry, dry depth 2”	>61	20
Cement Stabilized	Visibly dry, no puddles	>61	20
Either	Damp to wet	N/A	4

Note: Average of all eight “mean decel (in %g) readings.

Table D.8. Correlation Between Soil Type and RCR

Soil Type	USCS Classification	Water Content	C-17 RCR
Well Graded Gravels	GW	Dry	20
Clean Sands (< 5% fines)	SW, SP	Dry	22
Clayey Sands, Silty Sands (>12% fines)	SC, SM	Dry	22
Low Plasticity Clays & Silts	CL, ML	Dry	23

D.6.2.1. Mean Deceleration Measurements from Measured Skid Distance. If a Bowmonk unit is not available or if the unit should malfunction in the field, this procedure can be used to obtain an RCR value. The skidding and distance measurement procedure as described in the operational paragraph D.3.5.6, "Verification by Direct Measurement of Skid Distance," should be followed. Actual skid tests should be conducted in the number described in paragraph D.4.2, "Number of Tests Required," and in the test patterns shown in Figure D.9. Skidding tests should be conducted as described in paragraph D.5, "Performing Skid Test." Skid speeds of 40 mph should be used. Once testing is complete each skid distance measurement is converted to a mean deceleration value as described in paragraph D.3.5.6, "Verification by Direct Measurement of Skid Distance," and shown in Table D.4. The overall average for these mean deceleration values is then calculated. This average mean value is compared to column three of Table D.7 to determine the equivalent C-17 RCR value.

D.6.2.2. Correlation with Soil Type/Classification. In lieu of collecting any actual skid test data on the airfield surface, the characteristic friction parameter (RCR) may be estimated based on soil type and classification or strength data collected to assess the structural suitability of the airfield. This method is the least accurate and should only be used as a last resort. Appendix A provides the soil test methods that should be used to determine the soil type in the field. Table D.8 provides the correlation used to estimate RCR.

D.7. Rolling Friction Estimation. The rolling friction factor is important when the unsurfaced airfield is soft enough to produce appreciable loose till. The aircraft must “plow” through this loose till and this produces a requirement for slightly longer takeoff distances. This loose till depth should be measured at five locations on the runway in accordance with the measuring procedures described in Appendix B. Suggested measurement locations include; touchdown area, initial braking zone, point of rotation, departure end of runway, and other areas where the surface may be softened due to poor drainage, improper construction, aircraft turning, etc. Calculate the average of these five till depth measurements to establish the overall runway till depth, then refer to Table D.9 to determine the approximate rolling friction factor for the runway surface measured.

Table D.9. Rolling Friction Guidance

Semi-prepared Runway	Dry Till Depth	Rolling Friction Factor
Unstabilized (dry)	0 to 1.0 inches	5
	1.1 to 2.0 inches	10
	2.1 to 2.5 inches	15
	2.6 to 3.25 inches	20
	>3.25 inches	Maintenance Required
Unstabilized (damp to wet)	TBD	TBD
Cement stabilized	0.0 to 0.5 inches	2

Appendix E

Special Tactics Team Checklist

E.1. Current operator checklists used by AFSOC Special Tactics Teams (STTs) to verify suitability of semi-prepared airfields for C-17 operations should be updated to reflect the guidance given in this ETL, which supersedes the criteria contained in AFJPAM 32-8013, FM 5-430, Volumes 1 and 2 , Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations, in regards to C-17 airfield criteria.

E.1.1. Chapter 3, page 7B, C-17 Characteristics/ Airfield Data should be updated to reflect the following:

Runway	
Length	3,500*
Width	90
Width (180 TURN)	165
Lateral Safety Zone	35
Obstruction Slope	5:1
Overruns	
Length	300
Width	90
Weights	
Operating Wt, Empty	279,000
Max Landing Wt (Paved)	586,000
Max Landing Wt (AM-2)	560,000
Max Landing Wt (Semi-prepared)	447,000
Wind Limits	
Max Wind	TBD
Tailwind	TBD
Crosswind	30

Single Point Refuel Panel	
Nose to Spr	Unk
Side	Right
Turnarounds	
Length	180
Width	165
Taxiway	
Distance: RWY centerline to TXY edge	280
Width	60
Turn Radius	90
Shoulder	10
Clear Area	70
Apron	
Distance: Apron edge to fixed object	100

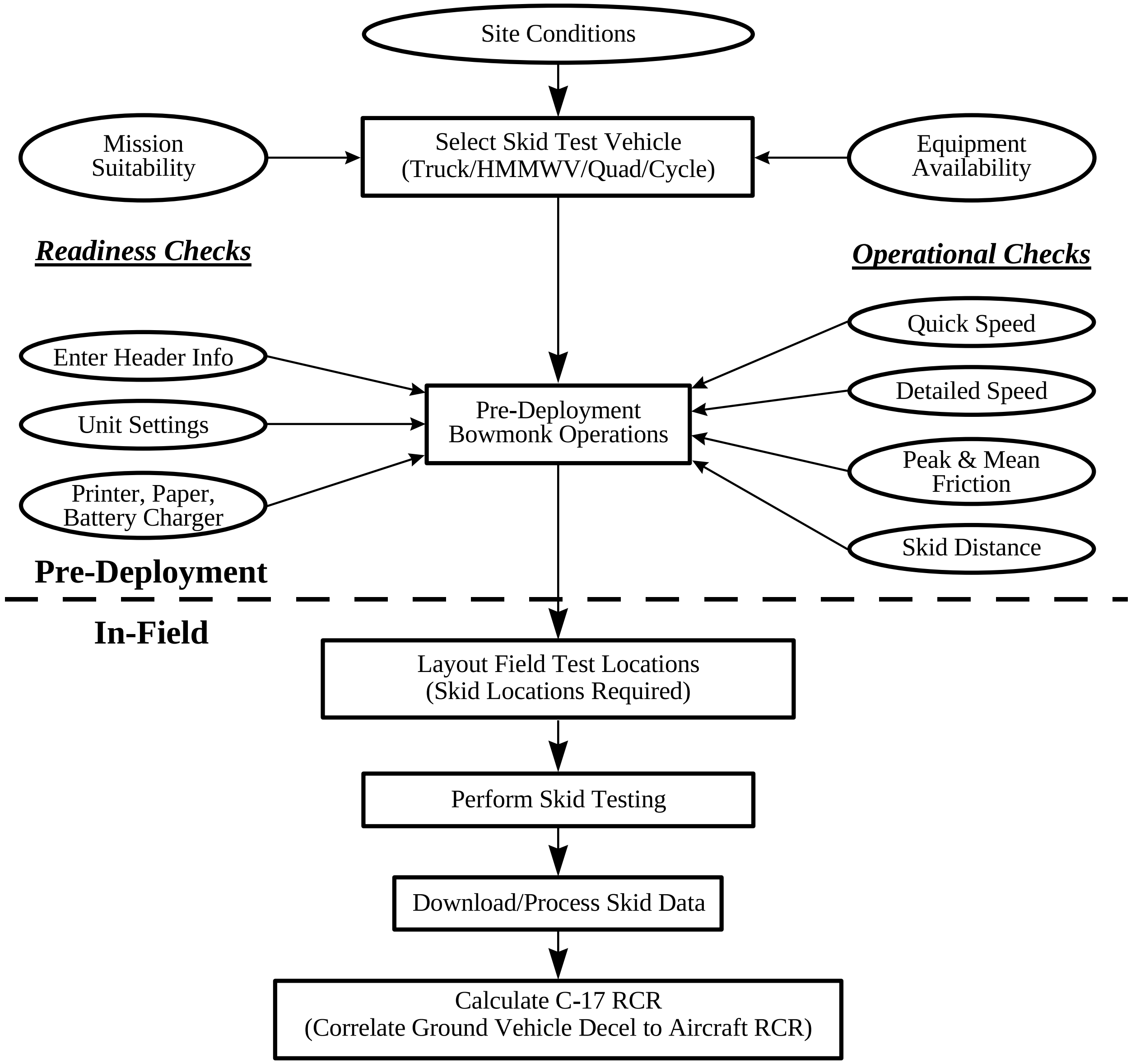
***Runway length of 3,500 ft for locations 0 to 6,000 ft Pressure Altitude. This requirement assumes an RCR of 20, 90°F (Ambient temperature = Standard (1962) + 31°F), and a Landing gross weight of 447,000 pounds. Using the same temperature and weight assumptions, the different RCRs will influence the required runway lengths as follows:**

RCR	Pressure Altitude (ft)	Runway Length (ft)
20	0 - 6,000	3,500
16	0 - 2,000	3,500
	2,001 - 5,000	4,000
	5,001 - 6,000	4,500
12	0 - 2,000	4,000
	2,001 - 5,000	4,500
	5,001 - 6,000	5,000
8	0 - 3,000	5,000
	3,001 - 5,000	5,500
	5,001 - 6,000	6,000

Note: These runway lengths **do not** include under/overruns.

E.1.2. Annex A, appendix 2-1, Airfield Survey Data should be updated as follows:

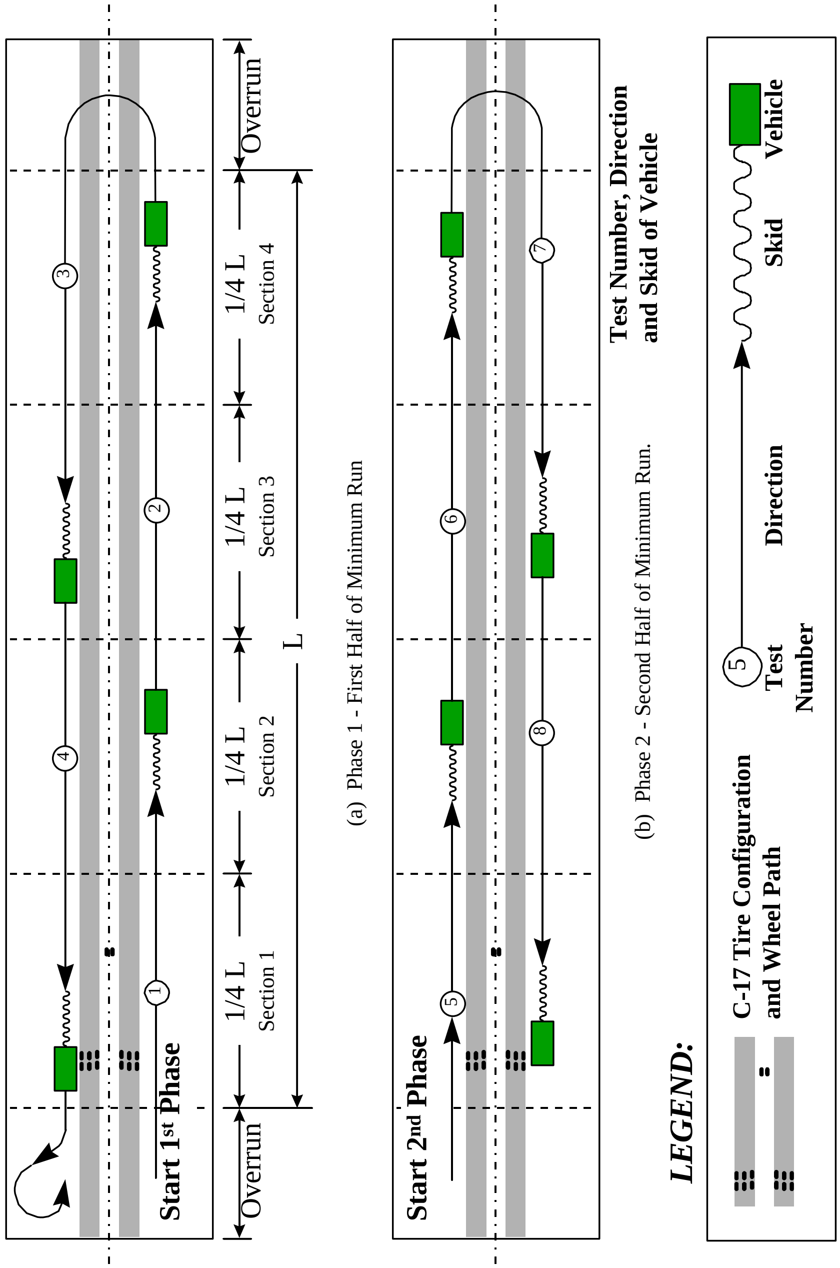
E.1.2.1. RCR Values. The following charts / procedures related to friction measurement should be included in the checklist:



Flowchart of the Recommended Friction Procedure

(15 October 1997)

Layout Field Test Locations. The goal of the field tests is to accurately characterize the on-site friction supply (or skid resistance) of an unpaved airfield. In order to meet this goal, an adequate number of skid tests should be conducted in several locations on the airfield that, when averaged, will adequately represent the skid resistance of the runway surface.



Required Skid Test Locations

(15 October 1997)

Number of Tests Required. Preliminary analysis of the research data has shown that the number of tests required for the typical contingency airfield (4000'x90') (as an example) should be as follows:

Number of Tests	Confidence Level	Time to Complete
8	Minimum Required	20 Minutes
16	Standard	35 Minutes
24 or more	Desired	50 Minutes or more

Target Speed at Braking. The absolute best speed for skid testing would be the speed of the aircraft when it touches down (approximately 135 mph), but this is not safe or practical for ground vehicles on a short dirt landing strip. The following target speeds are recommended for operational skid testing; 40 mph for the HMMWV, 6-Pax, quad, and cycle. Please note that the cycle does not have a speedometer or tachometer, so the operator must use their best judgment when using this test vehicle.

Braking Procedure. For the HMMWV and 6-Pax, push on the brake as hard as possible to lock up all four tires and then skid to a complete stop. For the cycle and quad, it was unsafe to lock up both the front and back brakes so the procedure to be used for all tests is locking up the back brakes only.

Runup Lengths and Stopping Distances. Notice also that there is a certain required runup length for each skid test. The evaluator should think through the test sequence after arriving on-site and carefully plan the skid test locations to achieve maximum efficiency and avoid aborted test runs because he/she ran out of room before they reached desired test speed. For planning purposes, with 40 mph test speeds, the following table is provided:

Skid Vehicle	Runup Length Required	Maximum Required Stopping Distance (ft)
HMMWV	1400	300
6-Pax	1200	250
Quad	1000	175
Cycle	700	125

Friction Test Procedure/Bowmonk Operation. Any of the following items in bold are extremely important and must be followed.

1. Align test vehicle with runway on one of the two longitudinal test lines previously identified; (i) 30 feet to the left of centerline or (ii) 30 feet to the right of centerline. **Both vehicle and tires should be straight.**

2. Turn unit on by pressing [RESET], letting unit go through self check. Unit will display 'AFM2 READY' once self check is complete.jArm Bowmonk device for test. Device should be armed just prior to vehicle acceleration. **If device is armed and a delay of more than 15 seconds occurs, device should be reset and then rearmed.**
3. Press button "A" to arm for first friction test. Check to be sure display shows 'SET FOR TEST #1 ?' (on first line), or whatever test number is being conducted. 'ENTER TO ACCEPT' will be displayed on line two.
4. Press [ENTER] to accept.
5. The display will now show 'RUNWAY ID'.
6. Press and hold [ENTER] until unit beeps at least twice. Release [ENTER] button.
7. Display will show 'PLEASE WAIT' for several seconds.
8. Then display will show 'ARMED FOR TEST #1' (on first line). Second line will display 'SPEED = 0'.
9. **Begin vehicle acceleration smoothly but quickly. Acceleration should be uniform without spinning tires or excessive vehicle bounce.** Proceed down runway, accelerating uniformly to target test speed. Unit will indicate current speed.
10. Once test speed has been reached, maintain uniform speed for 2 seconds.
11. Perform skid test. Apply full-braking until coming to a complete stop. Unit will display 'DON'T MOVE - CALCULATING'. **Keep the vehicle stationary to allow the unit to complete its internal calculations and display results.** This is particularly important with the motorcycle and quad.
12. Nominal steering will be required. **If the vehicle twists more than 15 degrees from the longitudinal line, then the test must be repeated.**
13. Unit will now display measured 'PERCENT G' (on first line) and 'SPEED' (on second line).
14. If the results are acceptable, save the test results by pressing [A] to accept this test. The unit will now display 'ARM2 READY'.
15. If the result is not acceptable, press the [RESET] button, the instrument will discard the current test and display 'AFM2 READY'. Another test can be performed and saved with the same test number.
16. Ready vehicle for next test and repeat from step 2 to perform subsequent tests. Continue until desire number of friction tests are completed. **The Bowmonk device will automatically shut down after 4 minutes of inactivity to save the battery. To turn it back on, simply hit the [RESET] button.**
17. Print out Bowmonk data and/or download to computer.

Stopping Friction Guidance (Preliminary)

Semi-prepared Runway	Surface Condition	HUMVEE Bowmonk Reading (at 40 mph)*	RCR
Unstabilized	Visibly dry, dry depth 2”	>61	20
Cement Stabilized	Visibly dry, no puddles	>61	20
Either	Damp to wet	N/A	4

Note: Average of all eight “mean decel (in %g) readings.

Alternate Friction Prediction Procedures. There are two alternate friction prediction procedures; correlating the soil type to RCR and directly measuring the skid distance with a ground vehicle and correlating to RCR. Neither method has as much accuracy as the Bowmonk Decel method, but can be used to obtain the RCR.

Correlation with Soil Type/Classification. In lieu of collecting any actual skid test data on the airfield surface, the characteristic friction parameter (RCR) may be estimated based on soil type and classification or strength data collected to assess the structural suitability of the airfield. Appendix A provides the soil test methods that should be used to determine the soil type in the field. Table D-3 provides the data correlation obtained.

Soil Type	USCS Classification	Water Content	C-17 RCR
Well Grade Gravels	GW	Dry	20
Clean Sands (< 5% fines)	SW, SP	Dry	22
Clayey Sands, Silty Sands (>12% fines)	SC, SM	Dry	22
Low Plasticity Clays & Silts	CL, ML	Dry	23

Correlation Between Soil Type and RCR

Direct Measurement Of Skid Distance. In lieu of collecting skid test data with the Bowmonk AFM-2, the actual skid distance may be physically measured. The following procedure can be used to measure the average braking friction of any vehicle used. This provides the user with a method to determine airfield friction should a Bowmonk unit not be available or working improperly. Comparison of measured skid distance (converted into an average friction) with the value calculated by a Bowmonk unit may also be used in the field as a method of checking the unit for proper operation.

Stopping Distance (ft)	20 MPH	30 MPH	40 MPH	50 MPH	60 MPH
15	90	NA	NA	NA	NA
20	67	NA	NA	NA	NA
25	54	NA	NA	NA	NA
30	45	101	NA	NA	NA
35	38	86	NA	NA	NA
40	34	76	NA	NA	NA
45	30	67	NA	NA	NA
50	27	61	NA	NA	NA
55	24	55	98	NA	NA
60	22	50	90	NA	NA
65	21	47	83	NA	NA
70	19	43	77	NA	NA
75	18	40	72	NA	NA
80	17	38	67	NA	NA
85	16	36	63	99	NA
90	15	34	60	93	NA
95	14	32	57	88	NA
100	13	30	54	84	NA
105	13	29	51	80	NA
110	12	28	49	76	NA
115	12	26	47	73	NA
120	11	25	45	70	NA
125	11	24	43	67	97
130	10	23	41	65	93
135	10	22	40	62	90
140	10	22	38	60	86
145	9	21	37	58	83
150	9	20	36	56	81
155	9	20	35	54	78
160	8	19	34	53	76
165	8	18	33	51	73
170	8	18	32	49	71
175	8	17	31	48	69
180	7	17	30	47	67
185	7	16	29	45	65
190	7	16	28	44	64
200	7	15	27	42	61
210	6	14	26	40	58
220	6	14	24	38	55
230	6	13	23	37	53
240	6	13	22	35	50
250	5	12	22	34	48
275	5	11	20	31	44
300	4	10	18	28	40
325	4	9	17	26	37
350	4	9	15	24	35
375	4	8	14	22	32
400	3	8	13	21	30
425	3	7	13	20	28
450	3	7	12	19	27
500	3	6	11	17	24
550	2	6	10	15	22
600	2	5	9	14	20
650	2	5	8	13	19
700	2	4	8	12	17

*Values in Table are in units of percent g.

AVERAGE FRICTION VS BRAKING DISTANCE

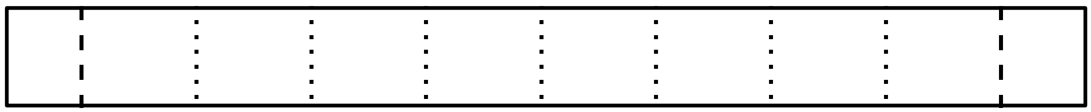
E.1.2.2. Condition Survey/Maintenance Data. The following charts should be included in the checklist:

OVERRUN

Runway Layout

500’ Sections (Coincide with Markers)

OVERRUN



Distress Locations

By Section

Distress Types

91 Potholes										
92 Ruts										
93 Loose Aggregate										
94 Dust										
95 Rolling Resistant Mat.										
96 Jet Blast Erosion										
97 Stabilized Layer Failure										

Distress Locations

Additional Features/Sections: Taxiways, Aprons, Turnarounds, Etc...

Identify Features/Section

Distress Types

91 Potholes										
92 Ruts										
93 Loose Aggregate										
94 Dust										
95 Rolling Resistant Mat.										
96 Jet Blast Erosion										
97 Stabilized Layer Failure										

Distress Severity Levels

Distress Types	GREEN	AMBER	RED
91 Potholes	< 3" Deep and/or <15" Diameter	3" to 6" Deep and >15" Diameter	> 6" Deep and >15" Diameter
92 Ruts	Exist but < 3" Deep	3" to 6" Deep	>6" Deep
93 Loose Aggregate	Covers < 1/10 of section	Covers between 1/10 and 1/2 of section	Covers > 1/2 of section
94 Dust	Does not obstruct visibility	Partially obstructs visibility	Thick, obstructs visibility
95 Rolling Resistant Mat.	Exist but < 3" Deep	3" to 6" Deep	> 6" Deep
96 Jet Blast Erosion	Exist but < 1" Deep	1" to 3" Deep	> 3" Deep
97 Stabilized Layer Failure	Exist but < 1" Deep	1" to 3" Deep	> 3" Deep

Note: Potholes, ruts, and rolling reistant material are considered major distresses. Depending upon actual distress location, any of these distress types categorized as RED may cause overa airfield condition to be RED.

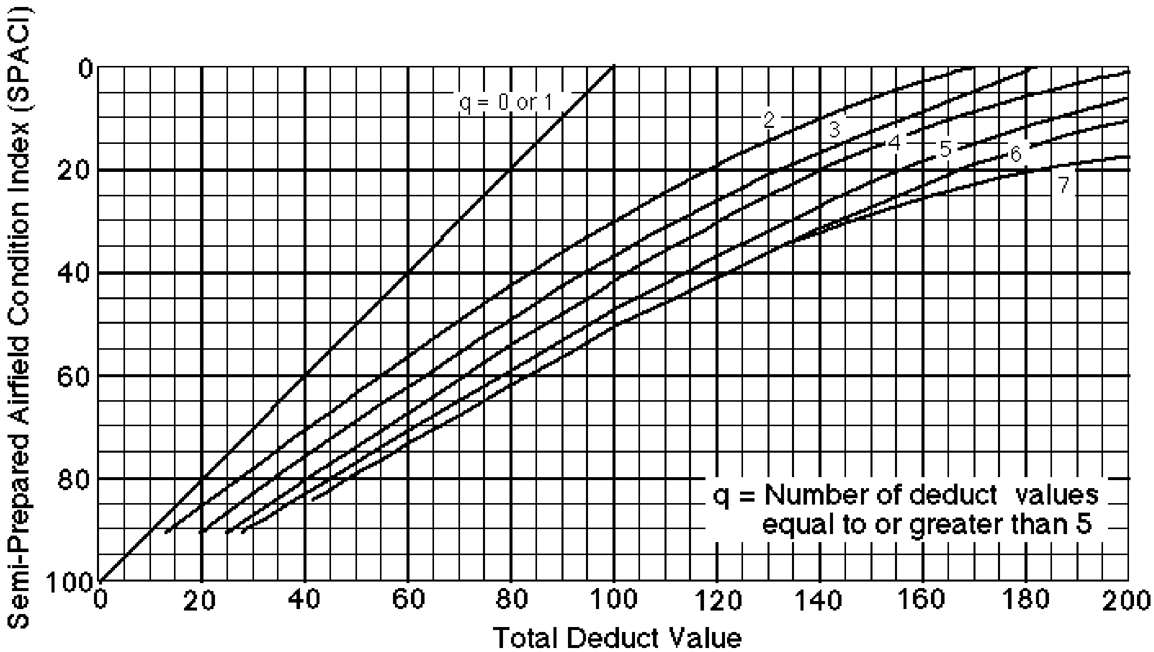
Rolling Friction Guidance

Semi-prepared Runway	Dry Till Depth	Rolling Friction Factor
Unstabilized (dry)	0 to 1.0 inches	5
	1.1 to 2.0 inches	10
	2.1 to 2.5 inches	15
	2.6 to 3.25 inches	20
	>3.25 inches	Maintenance Required
Unstabilized (damp to wet)	TBD	TBD
Cement stabilized	0.0 to 0.5 inches	2

Deduct Values for C-17 Contingency Operations

	Green		*Amber*		*Red*	
Distress	*R/T**	*H/A***	*R/T*	*H/A*	*R/T*	*H/A*
91 Potholes	4	2	10	6	20	12
92 Ruts	14	4	18	6	24	10
93 Loose Aggregate	4	15	6	30	8	45
94 Dust	2	15	4	30	6	45
95 Rolling Resistant Material	18	2	22	4	26	15
96 Jet Blast Erosion	5	10	10	30	15	40
97 Stabilized Layer Failure	5	15	10	25	15	35

*R/T Runways and taxiways. **H/A Hammerheads and aprons.

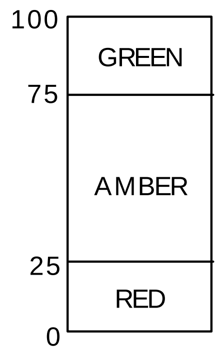


Correction Curves for Total Deduct Values

Enter bottom of chart with the total of all deduct values determined for each distress.

Extend line vertically until it intersects the correct "q" line (number of individual distress deduct values that are equal to or greater than 5).

At this point, draw line horizontally to determine the Semi-prepared Airfield Condition Index (SPACI).



SPACI Scale

E.1.2.3. Soil Identification. The following charts related to field soil characterization should be included in the checklist.

Soil Groups	**Symbol**
Gravel	G
Sand	S
Silt	M
Clay	C

Soil Characteristics	**Symbol**
Well graded	W
Poorly graded	P
High compressibility	H
Low compressibility	L
Organic (peat)	Pt
Organic (silts and clays)	O
Liquid limits under 50	L
Liquid limits over 50	H

Soil Groups/Symbols

Size Group	Passing	Retained On	Example
Boulders	No Maximum Size	12 Inch	
Cobbles	12 Inch	3 Inch	
Gravels	3 Inch	No. 4	Lemon to Pea
(Coarse)	3 Inch	3/4 Inch	Lemon to Walnut
(Fine)	3/4 Inch	No. 4	Walnut to Pea
Sands	No. 4	No. 200	Pea to Powdered Sugar
(Coarse)	No. 4	No. 10	Pea to Rock Salt
(Medium)	No. 10	No. 40	Rock Salt to Table Salt
(Fine)	No. 40	No. 200	Table Salt to Powdered Sugar
Fines	No. 200	No Minimum Size	(Not discernible to naked eye)

Grain Size Groups

Steps for Field Identification:

1. Select representative sample of soil (approximately 1 pint).

2. Separate gravel size particles from remainder of soil (approximately 1/8 to 3/16 inch and above).

- Gravel > 50% = GW, GP, GM, GC
- Gravel < 50% = SW, SP, SM, SC or fine-grained ML, MH, CL, CH, OL, OH

3. Estimate % fines (< 200 sieve) in original sample (sedimentation test may be helpful).

- For gravels
  - **if < 10% fines = GW or GP**
  - **if > 10% fines = GM or GC**
- For Sands
  - **if < 10% fines = SW or SP**
  - **if > 10% fines = SM or SC**
- **If > 50% of entire sample < 200 sieve = ML, MH, CL, CH, OL, OH**

4. For gravels and sands with < 10% fines (GW, GP, SW, SP) **check gradation to determine if well-graded or poorly-graded.**

- Wide range in grain sizes, with all intermediate sizes substantially represented **= GW or SW**
- Predominantly one size or some intermediate size missing (uniform or gap graded) **= GP or SP**

5. For fine-grained soils (ML, MH, CL, CH, OL, OH) **test for organic matter**

- If distinctive color, odor, spongy feel, or fibrous texture (particles of vegetation) **= OL or OH**
- If not, then **= ML, MH, CL, CH**

6. For fine-grained soils (ML, MH, CL, CH, OL, OH) **and coarse-grained soils with > 10% fines** (GM, GC, SM, SC).

- **Remove all material > 40 sieve**
- **Perform field plasticity tests on portion < 40 sieve to determine cohesive and plastic characteristics**
- **Results will be as given for each test**
- **Perform tests as required, until results are conclusive**

Field Identification of Soils						
Test	Material	Soil Types				
		ML	MH	CL	CH	OL/OH
Dry Strength	< 40 Sieve Wet	no to low	low to med	med to high	very high	low
Roll/Thread	< 40 Sieve Sticky	low	low to med	med	high	spongy
Ribbon	< 40 Sieve Sticky	no cohesion	little cohesion	3" to 8"	8" to 10"	
Wet Shake	< 40 Sieve Sticky	slow to rapid	no to slow	no to slow	no	
Cast	Damp	handle freely		handle roughly		
Bite/Feel	< 40 (< 200) Sieve	unpleasant		smooth		
Shine		Dull			Shine	
Wash		discolors quickly, > 5% silt				
Dust		> 10% silt				
Sedimentation		30 Seconds		1 Hour		

Summary of Field Plasticity Tests Results to Determine Soil Types

<table>
<tr><th colspan="3">Major Divisions</th><th>Symbol</th><th colspan="3">Field Identification Procedures
(Base fractions on estimated weights)</th></tr>
<tr><td rowspan="8">Coarse-grained Soils
More than half of material is larger than No. 200 sieve</td><td rowspan="4">Gravels
More than half of coarse fraction is larger than No. 4 sieve</td><td rowspan="2">Gravels
<5%
Fines</td><td>GW</td><td colspan="3">Wide range in grain sizes, all intermediate sizes substantially represented</td></tr>
<tr><td>GP</td><td colspan="3">Predominantly one size or some intermediate sizes missing</td></tr>
<tr><td rowspan="2">Gravels
>12%
Fines</td><td>GM</td><td colspan="3">Nonplastic fines or fines with little plasticity (see ML below)</td></tr>
<tr><td>GC</td><td colspan="3">Plastic fines (see CL below)</td></tr>
<tr><td rowspan="4">Sands
More than half of coarse fraction is smaller than No. 4 sieve</td><td rowspan="2">Sands
<5%
Fines</td><td>SW</td><td colspan="3">Wide range in grain sizes, all intermediate sizes substantially represented</td></tr>
<tr><td>SP</td><td colspan="3">Predominantly one size or some intermediate sizes missing</td></tr>
<tr><td rowspan="2">Sands
>12%
Fines</td><td>SM</td><td colspan="3">Nonplastic fines or fines with little plasticity (see ML below)</td></tr>
<tr><td>SC</td><td colspan="3">Plastic fines (see CL below)</td></tr>
<tr><td rowspan="8">Fine-grained Soils
More than half of material is smaller than No. 200 sieve</td><td rowspan="2" colspan="2"></td><td rowspan="2"></td><td colspan="3">Identification Procedures
on Fractions smaller than No. 40 sieve</td></tr>
<tr><td>Dry Strength</td><td>Wet Shake</td><td>Thread or Ribbon</td></tr>
<tr><td rowspan="3" colspan="2">Silts & Clays
LL <50</td><td>ML</td><td>None to slight</td><td>Quick to slow</td><td>None</td></tr>
<tr><td>CL</td><td>Medium to high</td><td>None to very slow</td><td>Medium</td></tr>
<tr><td>OL</td><td>Slight to medium</td><td>Slow</td><td>Slight</td></tr>
<tr><td rowspan="3" colspan="2">Silts & Clays
LL >50</td><td>MH</td><td>Slight to medium</td><td>Slow to none</td><td>Slight to medium</td></tr>
<tr><td>CH</td><td>High to very high</td><td>None</td><td>High</td></tr>
<tr><td>OH</td><td>Medium to high</td><td>None to very slow</td><td>Slight to medium</td></tr>
<tr><td colspan="3">Highly Organic Soils</td><td>Pt</td><td colspan="3">Readily identified by color, odor, spongy feel,
and frequently by fibrous texture</td></tr>
</table>

Unified Soil Classification System

Soil Types		Symbol		Value as Subbase or Subgrade	Value as Base Course	Potential Frost Action	Compressibility & Expansion
Coarse-grained Soils	Gravels and Gravelly Sands	GW		Excellent	Good	None to very slight	Almost none
		GP		Good to excellent	Poor to fair	None to very slight	Almost none
		GM	d	Good to excellent	Fair to good	Slight to medium	Very slight
			u	Good	Poor	Slight to medium	Slight
		GC		Fair to good	Poor	Slight to medium	Slight
	Sands and Sandy Gravels	SW		Good	Poor	None to very slight	Almost none
		SP		Fair to good	Poor to Not suitable	None to very slight	Almost none
		SM	d	Good	Poor	Slight to high	Very slight
			u	Fair to good	Not suitable	Slight to high	Slight to medium
		SC		Fair to good	Not suitable	Slight to high	Slight to medium
Fine-grained Soils	Silts and Clays LL <50	ML		Fair to poor	Not suitable	Medium to very high	Slight to medium
		CL		Fair to poor	Not suitable	Medium to high	Medium
		OL		Poor	Not suitable	Medium to high	Medium to high
	Silts and Clays LL >50	MH		Poor	Not suitable	Medium to very high	High
		CH		Poor to very poor	Not suitable	Medium	High
		OH		Poor to very poor	Not suitable	Medium	High
Highly Organic Soils		Pt		Not suitable	Not suitable	Slight	Very high

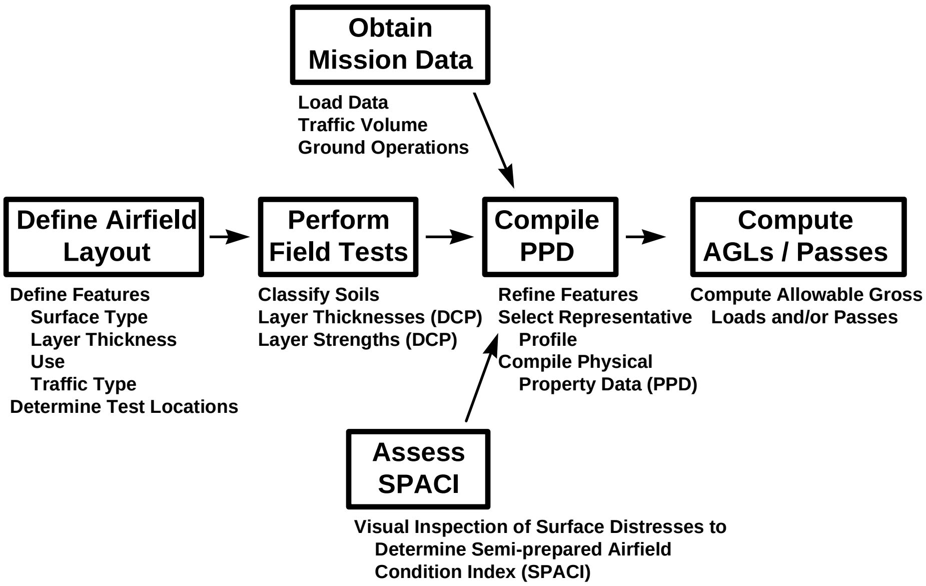
GM and SM groups are divided into subdivisions d and u for roads and airfields
Suffix d is used when LL $\leq$ 28 and PI $\leq$ 6 Suffix u is used when LL > 28

Soil Types		Symbol		Drainage Characteristics	Unit Dry Weight Lb per Cu Ft	Field CBR	Subgrade Modulus K Lb per Cu In
Coarse-grained Soils	Gravels and Gravelly Sands	GW		Excellent	125 - 140	60 - 80	300 or more
		GP		Excellent	110 - 130	25 - 60	300 or more
		GM	d	Fair to poor	130 - 145	40 - 80	300 or more
			u	Poor to impervious	120 - 140	20 - 40	200 to 300
		GC		Poor to impervious	120 - 140	20 - 40	200 to 300
	Sands and Sandy Gravels	SW		Excellent	110 - 130	20 - 40	200 to 300
		SP		Excellent	100 - 120	10 - 25	200 to 300
		SM	d	Fair to poor	120 - 135	20 - 40	200 to 300
			u	Poor to impervious	105 - 130	10 - 20	200 to 300
		SC		Poor to impervious	105 - 130	10 - 20	200 to 300
Fine-grained Soils	Silts and Clays LL <50	ML		Fair to poor	100 - 125	5 - 15	100 to 200
		CL		Impervious	100 - 125	5 - 15	100 to 200
		OL		Poor	90 - 105	4 - 8	100 to 200
	Silts and Clays LL >50	MH		Fair to poor	80 - 100	4 - 8	100 to 200
		CH		Impervious	90 - 110	3 - 5	50 to 100
		OH		Impervious	80 - 105	3 - 5	50 to 100
Highly Organic Soils		Pt		Fair to poor	-----	-----	-----

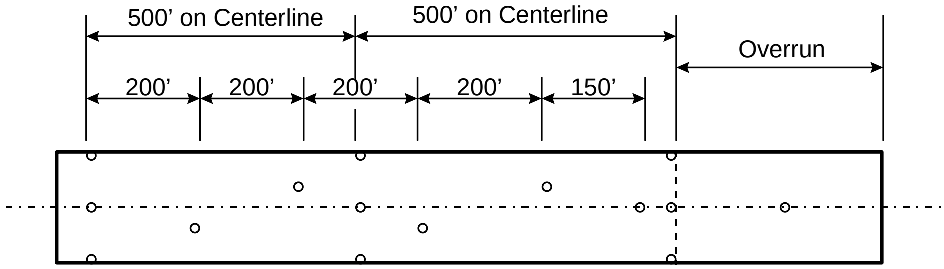
GM and SM groups are divided into subdivisions d and u for roads and airfields
Suffix d is used when LL $\leq$ 28 and PI $\leq$ 6 Suffix u is used when LL > 28

Soil Characteristics Pertinent to Roads and Airfields

E.1.2.4. Structural Evaluation. The following charts and procedures related to structural evaluation of the airfield should be included in the checklist.



Evaluation Process

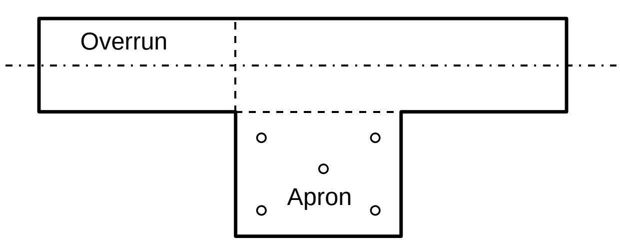


Note: For unimproved airfield, continue this pattern throughout the length. For aggregate surfaced airfields, the pattern may be more widely spaced on the remaining portion of the airfield.

Typical Semi-prepared Airfield

Priority Testing

1. Soft spots
2. Offsets, should be in wheel paths of main gear
3. Centerline
4. Aircraft turnarounds
5. Any area where the aircraft must stop
6. Overrun,one test in center
7. Along edges, at 500 feet intervals



Typical Apron or Turnaround

DCP Test Locations for Semi-prepared Airfields

Surface Layer Strengths. Lack of confinement at the top of the surface layer affects the DCP measurements. The penetration depth required to measure the surface layer strength accurately is related to the gradation and plasticity characteristics of the materials. The DCP can measure strengths of thin surface layers of fine-grained plastic materials but requires thicker surface layers for the non-plastic coarse-grained materials. The penetration depth required for measuring actual strength of the surface layer with the DCP varies with soil types as follows:

Soil Type	Average Penetration Depth (inches)
CH	1
CL	3
SC	4
SW-SM	4
SM	5
GP	5
SP	11

Note: The shearing action of the C-17 while braking during landing operations will create loose till on dry unstabilized soil surfaced runways in arid or semi-arid regions. The number of allowable passes may be significantly lower than those predicted using standard evaluation procedures. The DCP data collected at the top of the surface layer in the unconfined material, if treated as a separate layer in calculating allowable loads or passes, may provide a good indication of the surface capability to withstand the additional loads and stresses expected during landing operations.

Special Considerations:

1. DCP tests in highly plastic clays are generally accurate for depths to approximately 12 inches. At deeper depths, clay sticking to the lower rod may indicate higher CBR values than actually exist. Oiling the rod will help, without significantly impacting the test results. It may be wise to auger out the test hole after each 12 inch depth encountered to eliminate the clay related friction problems and allow more accurate measurements.

2. Many sands occur in a loose state. Such sands when relatively dry will show low DCP index values for the top few inches and then may show increasing strength with depth. The confining action of aircraft tires will increase the strength of sand. All sands and gravels in a “quick” condition (water percolating through them) must be avoided. Evaluation of moist sands should be based upon DCP test data.

3. If the cone does not penetrate significantly (approximately one-half inch) after 10 blows, the test should be stopped. **If the material encountered is a stabilized material or high strength aggregate base course which does not produce accurate results when penetrated with the DCP, it should be cored or augered through its depth and the DCP operation resumed beneath it.** An appropriate CBR

should be assigned to this layer. If large aggregate is encountered, the test should be stopped and a new test should be performed within a few feet of the first location. **The DCP is generally not suitable for soils having significant amounts of aggregate larger than 2 inches.** CBR values for unpenetrable materials must be carefully selected based upon their service behavior. Suggested CBR values for such materials are:

– Graded Crushed Aggregate	100
– Macadam	100
– Bituminous Binder	100
– Limerock	80
– Stabilized Aggregate	80
– Soil Cement	80
– Sand/Shell or Shell	80
– Sand Asphalt	80

DCP DATA SHEET							
BASE:		FEATURE:			DATE:		
TEST#:		TEST LOCATION:					
No of Blows (1)	Accum. Penetration mm (2)	Penetration p/Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)

(1) No. of hammer blows between test readings

(2) Accumulative cone penetration after each set of hammer blows

(3) Difference in accumulative penetration (2) at start and end of each hammer blow set

(4) (3) divided by (1)

(5) Enter 1 for 17.6 lb hammer, 2 for 10.1 lb hammer

(6) (4) x (5)

(7) From CBR versus DCP correlation (table C.2 or C.3)

(8) Previous entry in (2) divided by 25.4 rounded off to 0.2 in.

Suggested DCP Data Sheet

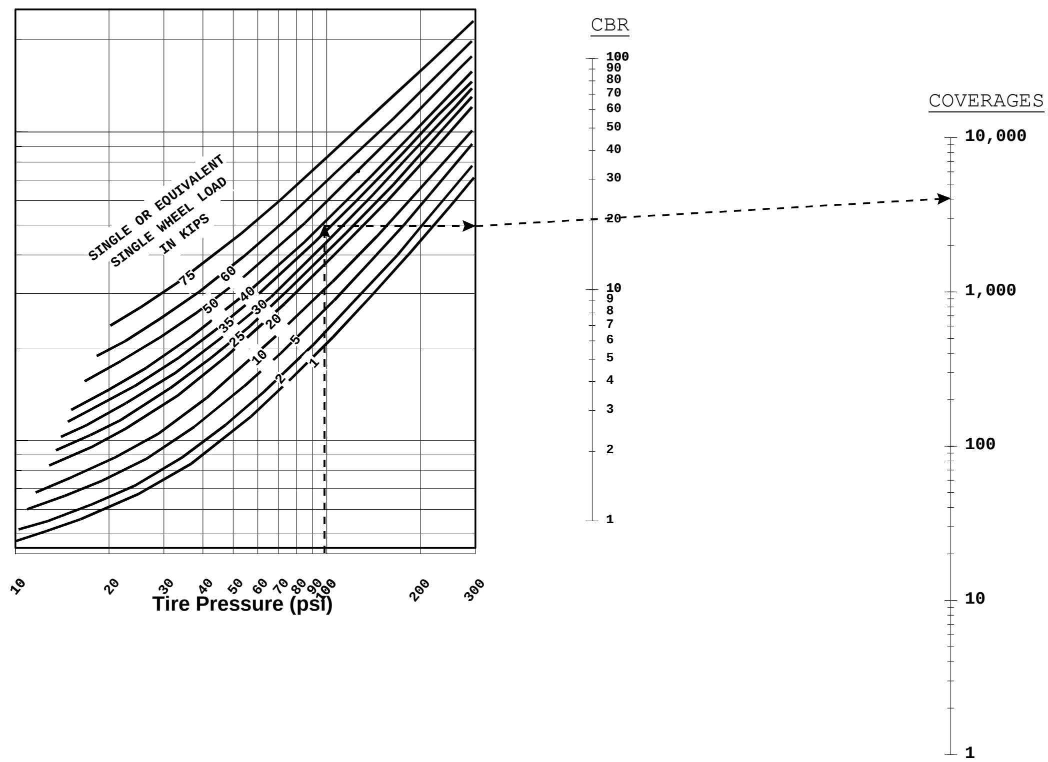
DCP Index mm/blow	in/Blow	CBR	DCP Index mm/blow	in/Blow	CBR	DCP Index mm/blow	in/Blow	CBR
<3	0.10	100	12		18	56-57	2.20	3.2
	0.11	92		0.50	17	58		3.1
	0.12	84	13		16	59-60		3.0
3		80	14	0.55	15	61-62	2.40	2.9
	0.13	76	15	0.60	14	63-64	2.50	2.8
	0.14	70	16	0.65	13	65-66	2.60	2.7
	0.15	65	17	0.70	12	67-68		2.6
	0.16	61	18-19		11	69-71	2.80	2.5
4		60	20-21	0.80	10	72-74		2.4
	0.17	57	22-23	0.90	9	75-77	3.00	2.3
	0.18	53	24-26	1.0	8	78-80		2.2
5	0.19	50	27-29		7	81-83		2.1
	0.20	47	30-34	1.20	6	84-87	3.40	2
	0.21	45	35-38	1.40	5	88-89	3.50	1.9
	0.22	43	39		4.8	92-96		1.8
	0.23	41	440		4.7	97-101	4.00	1.7
6		40	41	1.60	4.6	102-107		1.6
	0.24	39	42		4.4	108-114		1.5
	0.25	37	43		4.3	115-121		1.4
7	0.26	35	44		4.2	122-130	5.00	1.3
	0.27	34	45		4.1	131-140		1.2
	0.28	32	46	1.80	4	141-152		1.1
	0.29	31	47		3.9	153-166	6.00	1
8	0.30	30	48		3.8	166-183	7.00	0.9
9	0.35	25	49-50		3.7	184-205	8.00	0.8
	0.40	22	51	2.0	3.6	206-233	9.00	0.7
10-11		20	52		3.5	234-271	10.00	0.6
	0.45	19	53-54		3.4	272-324		0.5
			55		3.3	>324		<0.5

Tabulated Correlation of DCP Index vs CBR

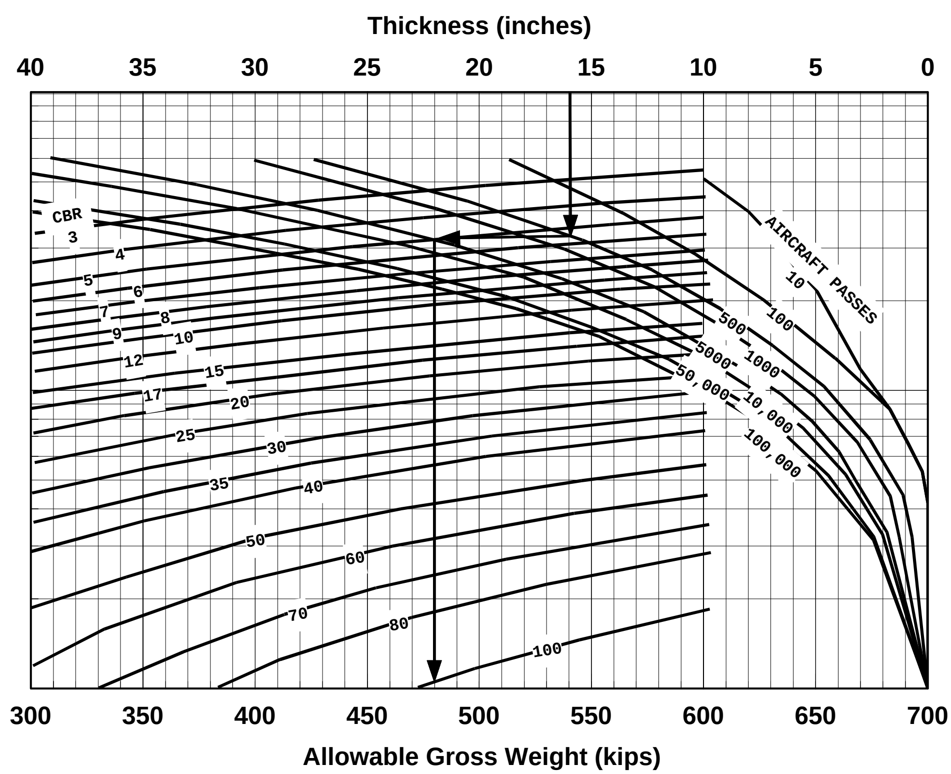
CH						CL					
DCP Index mm/Blow	in/Blow	CBR	DCP Index mm/Blow	in/Blow	CBR	DCP Index mm/Blow	in/Blow	CBR	DCP Index mm/Blow	in/Blow	CBR
10	0.4	35	115	4.5	3.0	19	0.7	9.6	40	1.6	2.2
15	0.6	23	120	4.7	2.9	20	0.8	8.6	41	1.6	2.1
20	0.8	17	125	4.9	2.8	21	0.8	7.8	42	1.7	2.0
25	1.0	14	130	5.1	2.7	22	0.9	7.1	43	1.7	1.9
30	1.2	12	135	5.3	2.6	23	0.9	6.5	44	1.7	1.8
35	1.4	10	140	5.5	2.5	24	0.9	6.0	45	1.8	1.7
40	1.6	8.7	145	5.7	2.4	25	1.0	5.5	46	1.8	1.6
45	1.8	7.7	150	5.9	2.3	26	1.0	5.1	47	1.9	1.6
50	2.0	7.0	155	6.1	2.3	27	1.1	4.7	48	1.9	1.5
55	2.2	5.3	160	6.3	2.2	28	1.1	4.4	49	1.9	1.4
60	2.4	5.8	165	6.5	2.1	29	1.1	4.1	50	2.0	1.4
65	2.6	5.4	170	6.7	2.0	30	1.2	3.8	51	2.0	1.3
70	2.8	5.0	>175	>6.9	<2.0	31	1.2	3.6	52	2.0	1.3
75	3.0	4.6				32	1.3	3.4	53	2.1	1.2
80	3.1	4.3				33	1.3	3.2	54	2.1	1.2
85	3.3	4.1				34	1.4	3.0	55	2.2	1.1
90	3.5	3.9				35	1.4	2.8	56	2.2	1.1
95	3.7	3.7				36	1.4	2.7	57	2.2	1.1
100	3.9	3.5				37	1.5	2.5	58	2.3	1.0
105	4.1	3.3				38	1.5	2.4	>59	>2.3	<1.0
110	4.3	3.2				39	1.5	2.3			

Tabulated Correlation of DCP Index vs CBR - CH and CL Type Soils

SUMMARY OF PHYSICAL PROPERTY DATA: SEMI-PREPARED AIRFIELDS													
FACILITY					SURFACE			SUBBASE			SUBGRADE		
FEAT	IDENT	LGTH (ft)	WDTH (ft)	COND	THC K (in)	DESCRP	CBR	THC K (in)	DESCRP	CBR	THC K (in)	DESCRP	CBR



Surface CBR Required for Aircraft Operations on Semi-prepared Airfields



Semi-prepared Surface Evaluation Curve, C-17

Aircraft	Gross Weight (kips)	Surface ESWL (kips)	Contact Tire Pressure (psi)	Pass/Coverage Ratio A Traffic
C-17	580	55.2	142	1.37
	500	47.5	122	
	450	42.9	110	
	425	40.5	104	
	400	38.1	98	
	350	33.3	84	

ESWLs and Tire Pressures for C-17 Aircraft

Note: A coverage differs from a pass. A pass simply represents an aircraft movement across a given point on the airfield; whereas, a coverage takes into account the fact that aircraft wander somewhat and the wheels do not follow the same identical path on each pass. To determine the number of passes multiply the number of coverages by the pass/coverage ratio for the aircraft and traffic area being evaluated.

Example: Determine the allowable number of passes for a 400,000 lb. C-17 aircraft on the following soil cross section:

8" Aggregate Surface Course, CBR: 20
Subgrade, CBR: 10

Solution:

- Step 1, Evaluate Surface Course Strength:
  - Enter the Surface CBR nomograph chart at 98 PSI, the expected contact tire pressure for the C-17.
  - Move vertically to the 38.1 ESWL curve and then horizontally to the right edge of the chart.
  - Draw a straight line from this point through the CBR line at 20 and read 4,000 coverages.
  - Multiply 4,000 coverages by 1.37 to determine the allowable number of passes, which is 5,480.
- Step 2, Evaluate Surface Layer Thickness/Subgrade CBR:
  - Select the Semi-prepared Surface Evaluation Curve for the C-17.
  - Enter the top of the chart at 8 inches drawing a vertical line (Line 1) downward through the aircraft pass curves.
  - Enter the bottom of the chart at 400,000 lbs and draw a vertical line up to the 10 CBR curve, then horizontally to intersect with Line 1.
  - The point of intersection indicates an allowable pass number of approximately 450.
- In this example, the subgrade layer results in the lowest allowable number of passes. The maximum allowable number of C-17 passes at a gross weight of 400,000 lbs is 450.

E.1.3. Annex A, appendix 2-2, Airfield Criteria should be updated to include C-17 specific criteria.

<u>Runway</u>	
Length	3,500*
Width	90
Longitudinal Gradient (%)	Max 3.0
Transverse Gradient (%)	0.5-3.0
Max Grade Change (%) per 200'	Max 1.5
Shoulder, Width	10
Shoulder, Transverse Gradient (%)	1.5-5.0
Lateral Clear Area, Width	35
Lateral Clear Area, Gradient(%)	2.0-5.0
Lateral Safety Zone, Width	50
Lateral Safety Zone, Slope	5:1
Overrun, Length	300
Overrun, Width	90
Aircraft Turnaround, Length	180
Aircraft Turnaround, Width	165, includes width of runway/overrun
End Clear Zone, Length	500
End Clear Zone, Inner Width	180
End Clear Zone, Outer Width	500
End Clear Zone, Max Gradient (%)	Max 5.0
Approach Zone, Length	Min 10,500 / Desired 32,000
Approach Zone, Inner Width	500
Approach Zone, Outer Width	2,500 at 10,500 length, is constant from 10,500 to 32,000
Approach Zone, Glide Ratio	20:1
APZ 1, Length	2,500
APZ 1, Width	500
<u>Taxiway</u>	
Width	60
Longitudinal Gradient (%)	Max 3.0
Transverse Gradient (%)	0.5-3.0
Shoulder, Width	10
Shoulder, Transverse Gradient (%)	1.5-5.0
Clear Area, Width	110 (from TXY centerline to obstacle)
Clear Area, Gradient (%)	Max 5.0
Turn Radii	90
Distance, RWY centerline to edge of TXY	280
<u>Apron</u>	
Gradient	1.5-3.0
Shoulder, Width	10
Shoulder, Transverse Gradient (%)	1.5-5.0
Distance, Apron Edge to Obstacle	100

E.1.4. Annex A, appendix 2-3, Airfield Layout should be updated to reflect a more detailed airfield drawing.